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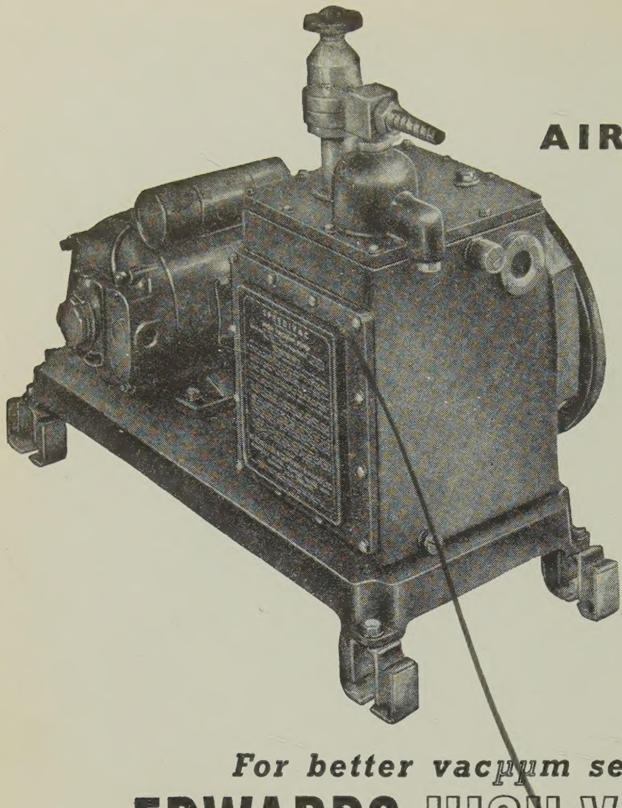

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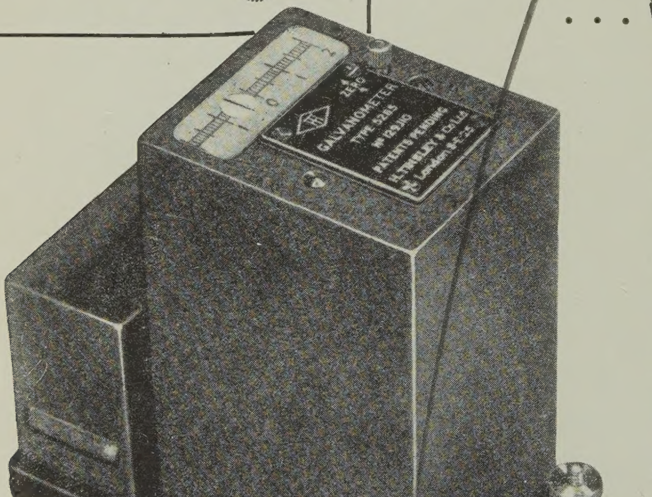

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SPECIAL ARTICLE

Silicones and their applications

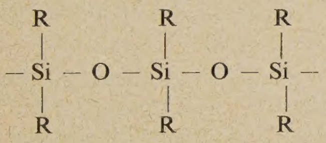
By J. AMES, B.Sc., Research Department, Imperial Chemical Industries Ltd., Nobel Division, Stevenston, Ayrshire

The characteristics of the polysiloxane chain are described, and their effects on the properties of silicones are discussed. Silicones possess excellent thermal stability over a temperature range of more than 300° C, low surface tension, good electrical properties and a high degree of water-repellency, and are effective as release agents. The mechanical properties of the condensed polysiloxanes are poorer than those of most organic polymers at moderate temperatures, but are markedly superior at extremes of temperature. Silicones are available in the form of fluids, rubbers and resins; the manufacture and properties of each are described, and their special applications are discussed.

GENERAL PROPERTIES OF SILICONES

ce they first became available in commercial quantities le more than ten years ago, silicones have been used in a at many technical processes. A recent publication(1) lists r 400 known applications in twenty separate industries. rsatility is a notable feature of the silicones as a class of ustrial materials, for they appear in several physically tinct forms and cover an astonishingly wide range of perties. It must be admitted that in certain respects these perties are inferior to those of competitive organic procts, though this is only true when the comparison is made moderate temperatures, for the capacity of silicones to rate under severe conditions is much superior to that of known organic polymer. Silicones are of course hybrids, ssessing inorganic as well as organic characteristics, and ir properties remain relatively constant over a far wider nperature range than is the case with purely organic comunds. This is their most important physical attribute, ugh in recent years silicones have become familiar to the neral public chiefly through the exploitation of less typical perties in certain household products.

Silicones are polymeric organo-silicon compounds conning the silicon-oxygen-silicon skeleton



$$-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-$$

e molecule (which is termed a polysiloxane) may be linear, clic or cross-linked, and the radical R may theoretically resent any organic grouping. As the organic radicals rease in size, however, the molecule begins to lose its ically inorganic features, and for this reason silicones with re than two or three carbon atoms in the side chain are erally of little interest (though the phenyl group provides exception to this general rule). Manufacturing difficulties ther limit the range of commercially available products nost exclusively to methyl, phenyl and vinyl polysiloxanes d their halogenated derivatives. The length of the polyxane chain, however, is not restricted, and materials nging from di-siloxane to polysiloxanes having a molecular ight greater than 10^6 are readily available.

The properties of silicones are largely the properties of the ysiloxane chain, influenced only slightly by the character the substituent group (when this contains only a few bon atoms). Good heat resistance might be expected from aterial whose basic structure resembles that of silica. The silicon–oxygen bond is partially ionic; from electronegativity values its degree of ionization has been estimated at 51% compared with only 22% for the corresponding carbon–oxygen bond.(2) The bonds are thus powerful dipoles which protect the adjacent hydrocarbon groups from chemical attack(3) and in consequence the methyl, ethyl, phenyl and vinyl polysiloxanes are highly resistant to oxidative degradation at temperatures up to 200° C. This protective action does not extend to carbon–carbon bonds at some distance from the dipole, however, and heat stability is quickly lost as the size of the hydrocarbon group increases. The silicon–oxygen bond itself, of course, has good thermal stability, but is relatively easily cleaved by concentrated acids and alkalis at room temperature, and dilute acids and alkalis at high temperatures.

Reported values of the silicon–oxygen–silicon bond angle vary considerably (with its large degree of ionization the directional character of the bond is correspondingly less), but it appears certain that the bond angle is large, probably between 140° and 160°, and that the siloxane linkage is highly flexible. The covalent radius of silicon is almost twice that of carbon, and thus the organic groups attached rigidly through silicon to the flexible siloxane chain sweep out a relatively large volume of space. The close approach of adjacent molecules is therefore restricted, and intermolecular attraction is consequently weak, so that the fluids have low surface tension, low viscosity/temperature coefficients, and low freezing points. Some adverse properties also result; the low pour point, the small viscosity changes with temperature and the low intermolecular forces mean that useful thermoplastic effects are not observed in the linear polymers; and the cross-linked and condensed polymers, the rubbers and resins, have only moderate mechanical properties and swell excessively in some organic solvents.

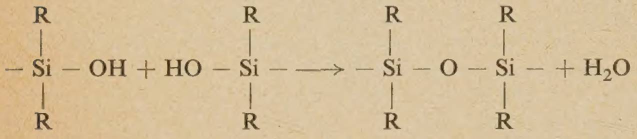
The weak intermolecular forces between the polysiloxane molecules account only partially for the excellent viscosity/temperature characteristics of silicone fluids, and it has been suggested(4) that the siloxane chain takes the form of a helix which uncoils with rising temperature. The increased length of the molecule then offers a greater resistance to motion, and the silicon–oxygen dipoles, which in the coiled form are internally compensated, exert a greater attraction; both these effects tend to counterbalance the decreased viscosity due to increased thermal agitation. When the substituent groups on silicon are large the ability to coil is restricted, and the compensating effect is correspondingly less; thus, methyl phenyl siloxanes have a greater temperature coefficient of viscosity than dimethyl siloxanes.(5)

The close packing of organic groups round the siloxane chain gives the silicones both anti-adhesive and hydrophobic properties. These properties are made more permanent under the influence of heat, since the molecule then uncoils and is able to attach itself through its semi-ionic skeleton to certain types of substrate while still presenting a free surface of water-repellent or non-adhesive groups. With some types of silicones these properties are further enhanced by cross-linking under the influence of heat.

The electrical properties of silicones are equivalent to those of good organic insulants at normal operating temperatures, but the merit of silicones in this field (as in most others) depends on the maintenance of these properties under adverse conditions. Their heat stability, for example, has enabled the operating limits for resinous or rubber-like insulants to be broadened considerably, and their resistance to moisture and to oxidation enables them to function under atmospheric conditions which would break down organic insulants.

MANUFACTURE

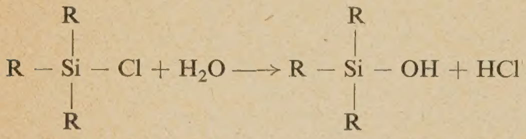
The preparation of silicones depends upon the condensation



$$-\overset{R}{\underset{R}{Si}}-OH + HO-\overset{R}{\underset{R}{Si}}- \longrightarrow -\overset{R}{\underset{R}{Si}}-O-\overset{R}{\underset{R}{Si}}- + H_2O$$

Condensation between hydroxyl groups on the same silicon atom does not occur, and condensation proceeds most readily when R is a small alkyl group or hydrogen. Under these conditions the reaction proceeds rapidly even at room temperature, particularly in the presence of acids. When larger alkyl groups or aryl groups are attached to silicon the reactivity of the silanol grouping is much reduced.

Silanols can readily be prepared by the hydrolysis of the appropriate chlorsilanes.



$$R-\overset{R}{\underset{R}{Si}}-Cl + H_2O \longrightarrow R-\overset{R}{\underset{R}{Si}}-OH + HCl$$

When the substituent group is small and conditions are acidic the silanols are difficult to separate before condensation occurs, and the hydrolysis and condensation are carried through as a single operation. The reactivity of the chlorine and hydroxyl substituents on silicon may be contrasted with the stability of these groups in substituted hydrocarbon compounds.

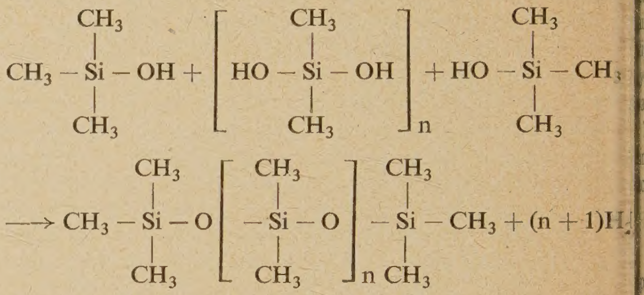
Chlorsilanes are thus important intermediates in the manufacture of silicones. In the laboratory they are most easily prepared by the Grignard Process

$$SiCl_4 + xRMgCl \longrightarrow R_xSiCl_{4-x} + xMgCl_2$$

but unfortunately the considerable amounts of ether which this process requires introduces considerable hazard on the large scale. The Grignard Process is, however, the most versatile process at present available, and it is frequently used in the manufacture of specialized products. Most commercial silicones are manufactured by the so-called Direct Process,(6) in which an alkyl or aryl chloride is reacted directly with powdered silicon metal at temperatures between 250° C and 280° C. The presence of finely divided copper or silver is necessary to promote the reaction, and the high temperatures involved restrict the process to the preparation of methyl or phenyl chlorsilanes. A mixed product is obtained, of which about 60% is the dichlorsilane, R_2SiCl_2, and t remainder chiefly the monochlorsilane, R_3SiCl, and t trichlorsilane, $RSiCl_3$, but side products are also invaria obtained in small quantities. In the manufacture of silico these chlorsilanes are hydrolyzed either singly in the pu state or in admixture in selected proportions, and the seco stage in manufacture therefore consists in the separation the three principal products. These boil in the range 57° 70° C and are separated by fractional distillation, which m be carried out in an inert atmosphere since the chlorosila react with moist air. These difficulties of manufacture le to considerable wastage and add appreciably to the price what is at present a somewhat costly commercial product.

By hydrolysis of chlorsilanes or mixtures of chlorsilan three general classes of silicones may be obtained:

Silicone fluids. Hydrolysis of dimethyl dichlorsilane gives polysiloxane (actually a mixture of polysiloxanes of differe molecular weights) which can be separated as a colourle oily fluid. The molecular weight and viscosity of the flu can be controlled (within limits) by including in the hydroly mix a pre-determined quantity of trimethylchlorsilane, whic being monofunctional, acts as an end-stopper to polysiloxa chains formed from dimethyl dichlorsilane.

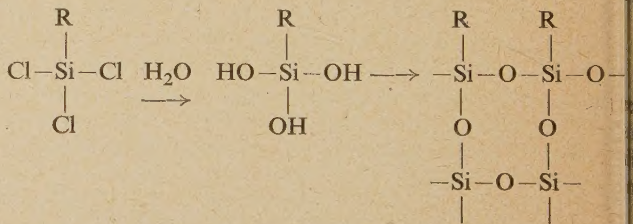


$$CH_3-\overset{CH_3}{\underset{CH_3}{Si}}-OH + \left[HO-\overset{CH_3}{\underset{CH_3}{Si}}-OH\right]_n + HO-\overset{CH_3}{\underset{CH_3}{Si}}-CH$$

$$\longrightarrow CH_3-\overset{CH_3}{\underset{CH_3}{Si}}-O\left[-\overset{CH_3}{\underset{CH_3}{Si}}-O\right]_n-\overset{CH_3}{\underset{CH_3}{Si}}-CH_3 + (n+1)H$$

Silicone gums. These are very high molecular weight line polysiloxanes, prepared by the hydrolysis of very pu dichlorsilanes or mixtures of dichlorsilanes. Mono- or t functional substances must be absent to avoid chain-stoppi or cross-linking. These gums, which are in effect fluids wi viscosities in the region of 10^7 centistokes, form the basis silicone rubbers.

Silicone resins. The resins differ from the fluids and the gu in their high degree of cross-linking. They are prepared hydrolysis of methyl or phenyl trichlorsilanes, usually wi the addition of dichlorsilanes to give products of improv flexibility.



$$Cl-\overset{R}{\underset{Cl}{Si}}-Cl \quad \underset{\longrightarrow}{H_2O} \quad HO-\overset{R}{\underset{OH}{Si}}-OH \longrightarrow \begin{array}{c} -\overset{R}{Si}-O-\overset{R}{Si}-O- \\ \quad O \qquad\quad O \\ -Si-O-Si- \end{array}$$

The hydrolysis is usually carried out in the presence of organic solvent to dissolve the resinous product.

PROPERTIES OF SILICONE FLUIDS

The silicone fluids are colourless, odourless materials low volatility and toxicity, characterized by excellent stabili at high temperatures. They are unaffected by heating

ıtact with the atmosphere at 150° C. At higher tem-
ratures, particularly at 200° C and over, the fluids slowly
in the presence of oxygen, probably due to cross-linking
tween adjacent organic groups. The change may be some-
at delayed by the addition of a suitable anti-oxidant such
N : N′–diphenyl–p–phenylenediamine, and the fluids may
n be held for several days at 250° C. When oxygen is
luded the operating temperature may be raised to 300° C;
tially some cleavage of the siloxane chain occurs at this
nperature, indicated by a fall in viscosity, but the fluid
ain appears to reach equilibrium after several hundred hours.
ble 1 gives heat ageing data for a typical 100 centistokes
° C) fluid.

ble 1. *Silicone fluid F.* 110/100*—change of viscosity on heating in nitrogen atmosphere*

Hours	72	144	240	336	480
% viscosity decrease	25	34	41	46	47

e fluids are resistant to many chemical reagents; hydrogen
roxide (3%), fatty acids, sulphur dioxide, phenols,
nmonium hydroxide, petroleum hydrocarbons and dilute
ueous mineral acids and bases are without effect, but con-
ntrated mineral acids and bases attack the siloxane chain
rly readily. In general the fluids are easily soluble in
phatic and aromatic hydrocarbons and in chlorinated
drocarbons. They are insoluble in ethanol, acetone and
ter.

Table 2 summarizes the physical properties of typical
nethyl siloxane fluids in the viscosity range 40–1000 centi-
kes.

Table 2. *Physical properties of silicone fluids*

ecific gravity (20° C)	0·964–0·969
ecific heat (27° C)	0·352–0·374
pansion coefficient (per ° C)	9·20 –9·80 × 10^{-4}
scosity temperature coefficient	0·588–0·599
ısh point	315° C–323° C
ur point	−49° C– −54° C
fractive index	1·4022–1·4036
at of combustion	6130 cal/g
rface tension	20·5–21·2 dyn/cm
rmittivity	2·7
wer factor (50 c/s)	0·009 at 25° C to 0·03 at 200° C
lume resistivity (500 V)	5 × 10^{15} at 20° C to 3 × 10^{14} at 200° C
ctric strength	>30 kV between 1 in. discs separated 0·1 in.

The small change in the viscosity of silicone fluids with
nperature is particularly striking when compared with the
cosity change in petroleum oils. Comparative data for a
nethyl silicone oil and a petroleum fluid SAE 30 are shown
Table 3.

ble 3. *Comparison of viscosities (centistokes) of silicone fluids and petroleum oils*

	120° C	*25° C*	*−25° C*
SAE 30(7)	6·6	250	70 000
ilicone fluid F. 110/100	24	140	450

phenyl siloxane fluids show a more rapid decrease in
cosity with increasing temperature than the dimethyl siloxanes of Tables 2 and 3, since the additional bulk of the phenyl group obstructs the coiling of the siloxane chain. The same factor, however, causes the freezing point of the phenyl siloxanes to be lower than that of the corresponding methyl fluids, and since the phenyl group has a better high temperature stability than the methyl group, the phenyl siloxanes can operate over a wider temperature range.

APPLICATIONS OF SILICONE FLUIDS

While the principal technical interest in silicone fluids is in the good thermal stability, electrical properties and viscosity/temperature characteristics, the main commercial developments have been based on their water-repellency, low surface tension, and release properties. The high cost of silicones has undoubtedly had a strong influence on this line of development, since the latter group of properties are surface properties whose effect can be attained with relatively small percentages of fluid, while the former are bulk properties which are somewhat sensitive to the presence of diluents. Thus, while silicone water repellents, for example, can compete both technically and economically with more established materials in the field, the use of silicone fluids in electrical and high temperature applications has in the main been limited to special products for which silicones are the only suitable materials available.

Textiles and leather applications. Silicones have aroused interest as water repellents for textiles and leather for more reasons than their good water-repellency, which is about the same as that of hydrocarbon compounds. (The contact angle for water on a dimethyl siloxane film is 103°(8) compared with 105° for water on paraffin wax.) Silicones, however, have two major advantages over most conventional treatments for proofing fibrous materials; the finish can be made semi-permanent, since certain of the fluids can be cross-linked to give flexible coherent films round the individual fibres; and the finish can be applied in such a dilution that only the fibres themselves are coated, leaving the interstices in the fabric open for the passage of water vapour but not of liquid water. The latter advantage is an important consideration in the proofing of clothing, since garments which do not "breathe" are uncomfortable to wear. In addition to water-repellency, silicones give textiles improved drape, handle and stain resistance.

Polishes. Silicones in polishes perform two functions: they reduce the work required to spread the polish, and they improve gloss. Silicone fluids are incompatible with waxes, and in consequence they act as lubricants between individual wax crystals. The high gloss results from the low intermolecular forces, which enables the silicone fluid to spread as a thin film over the polished surface. Apart from economic factors, the presence of hard wax is generally an essential in polish formulation, since surface irregularities must be filled in and a smooth surface prepared before a high gloss can be attained. A silicone fluid alone, with its great spreading capacity, would not be satisfactory for this purpose.

Release applications. In many cases adhesion between interfaces is due to chemical effects and can be reduced by appropriate chemical treatment, often by the application of a substance containing a long hydrocarbon chain. A disadvantage to this treatment is that when high temperatures are involved, as in most moulding operations, the release agent is very rapidly carbonized. The thermal stability and low cohesion of silicone fluids makes them ideal release agents in many hot moulding processes, and the large number of releases that can frequently be obtained from a single application of fluid more than compensates for the relatively high cost of the material.

Materials such as paper may also be treated with silicone fluids, when they acquire non-adhesive properties as well as a high degree of water-repellency. These products are used as interleaving layers between exhesive materials.

Lubricants. The efficiency of the silicone fluids as lubricants depends on the type of surface to be lubricated and the applied load. Their performance with plastics and rubber is excellent and certain metal combinations can be lubricated satisfactorily, but under boundary lubricating conditions they are poor lubricants for ferrous metal pairs. The adsorption of methyl or phenyl polysiloxanes on iron or steel is apparently weak, so that a coherent, condensed film is not formed between the sliding surfaces, and metal to metal contact occurs. Coefficients of friction are high—about 0·33 compared with 0·14 to 0·16 for petroleum oils(9)—and wear rates are excessive. Considerable improvement can be effected by the introduction of polar groups into the polysiloxane molecule to increase the degree of adsorption on the lubricated surfaces. The most widely studied substituents appear to have been halogenated phenyl groups, and coefficients of friction as low as 0·14 have been reported for siloxanes containing these substituents.(9) For commercial applications the nature of the polar group is of course limited both by its heat stability and the ease with which the substituted siloxane can be manufactured.

Although the unmodified methyl and phenyl siloxane fluids are ineffective under extreme pressure conditions with ferrous metal surfaces, there are nevertheless many high and low temperature applications for which their lubricating properties are adequate. They are used in shock absorbers, for example, in damping devices, and in precision instruments where a low viscosity/temperature coefficient and good heat stability is essential. They can also be compounded with filters such as silica and lithium soaps to form greases, which are used chiefly for stop-cock, valve and bearing lubrication. The high temperature stability of the grease depends upon the high temperature stability of the filler as well as that of the silicone.

Electrical applications. As dielectric fluids, silicones function in most respects at least as well as other liquid dielectrics. Where the electrical properties are slightly deficient, the thermal stability and good water-repellency often make them useful in special applications. Although their permittivity is somewhat low, for example, they are used in capacitors where operating conditions are severe. The greater operating temperatures made possible by the use of silicone fluids enables transformers of reduced dimensions to be operated without loss in rating. When the fluids are compounded with inert, finely divided materials such as silica, putty-like materials having dielectric properties similar to those of the parent polysiloxane result, and these are used as water-repellent sealing compounds in a variety of electrical applications.

SILICONE RUBBERS

Unlike the base polymers of natural and synthetic organic rubbers, the pure linear polysiloxanes at present available display no rubber-like properties. The intermolecular forces are sufficiently low for the polymer to retain the properties of a fluid even when the molecular weight exceeds 10^6, although the viscosities of such fluids are in the region
10^7 centistokes. The fluid, or gum, becomes elastic on
when it is cross-linked through organic groups of adjace
molecules, and the mechanical properties of the produ
compare unfavourably with those of cross-linked orga
polymers. Sulphur is not a very effective vulcanizing age
for silicone polymers, though its use has been described wi
methyl vinyl polysiloxanes(10), and cross-linking is usual
achieved by the use of certain organic peroxides, whi
dissociate into free radicals on heating. It is believed th
these free radicals remove hydrogen from the methyl grou
of polysiloxane molecules, and that pairs of methyle
radicals so formed then condense to form ethylene bridg
between adjacent polysiloxane molecules. The weak, rubbe
gel which results is of little practical value, but it can
substantially reinforced by the incorporation of suitab
fillers before curing, as natural rubber is reinforced
carbon black. Carbon black itself is not in general a sati
factory filler for silicone gums when organic peroxides a
used as curing agents, however, since the oxygen which
occludes tends to inhibit free radical formation. The fille
typically used for reinforcing silicone rubber are fine
divided silicas, silicates, inorganic oxides, and metal ca
bonates, but almost any filler appears to be effective provide
it is chemically inert, heat stable, and is in a sufficiently fi
state of subdivision. With the incorporation of suitab
fillers the tensile strength at break of silicone rubber can
increased from 100 lb/in.^{2} to more than ten times this value

The techniques of silicone rubber preparation are ve
similar to those used by fabricators of organic rubbe
Fillers, curing agents and any special ingredients are com
pounded with the silicone gum on standard rubber mills
incorporators, and the compound so formed can be moulde
extruded, calendered or coated on to cloth. A set cure
about 130° C is usually given, followed by a graduated curin
schedule at temperatures up to 250° C, depending upon t
use to which the end product is to be put. Unlike rubb
compounds based on natural rubber or synthetic orga
polymers, silicone rubbers have a very simple constitutio
and usually contain little more than gum, filler and curin
agent, but by changing the types and quantities of these com
ponents, properties may be varied widely. The introductio
of a small percentage of phenyl groups into the gum, fo
example, considerably reduces the brittle point temperatur
while a small degree of unsaturation in the polysiloxa
molecule improves compression set and solvent resistanc
and gives a faster cure. Hardness can be adjusted b
changing the quantity of filler, though this can only be do
within certain limits since other mechanical properties ma
be affected adversely. Finely divided fillers give good mecha
nical properties to the cured rubbers, while coarse fille
improve the ease of processing of the uncured stock.

Although the mechanism of rubber reinforcement has bee
widely studied, no satisfactory explanation of the relationshi
between filler and polymer has so far been propose
According to Warrick(11) the filler in silicone rubber form
only weak secondary bonds with the polymer, probably abo
equal in number to the total cross-links in the polymer, bu
making little contribution to tensile strength. The functio
of these secondary bonds is to enable a high elongation to
reached on stretching; the polymer molecules can thu
become more highly oriented than in the unfilled rubber, an
regions of crystallinity are formed, with the consequen
improvement in tensile strength. Filler particle size appea
to be critical, since the degree of reinforcement increase
sharply when filler diameter falls below about 500 Å, but th

tical diameter and the degree of reinforcement do not pend to any great extent on the type of filler used. Accord- ; to Warrick the ideal filler would therefore be of very all particle size and completely inert chemically. Blanchard d Parkinson,(12) however, maintain that in carbon black ed organic rubbers two types of filler/polymer bonds are rmed—weak, secondary bonds which are readily broken small stresses, and strong primary bonds which are not. is suggested that high tensile strength and good elastic operties result from a reduction of the number of secondary nds and the formation of a limited number of strong imary bonds. There is no reason to assume, of course, at the interaction between inorganic fillers and silicones is nilar to that between carbon black and organic rubbers, it studies of synthetic organic rubber filled with silica(13) ve produced some interesting results. Heat treatment of e rubber compound before curing greatly improved the odulus of the cured rubber and reduced the amount of on-reversible deformation which occurred on repeated cling, suggesting the formation of primary bonds at the pense of secondary forces.

Considerable advances have been made in recent years in e preparation of both gums and fillers for compounding icone rubber, and present-day products are relatively tough id durable. They are still very far from competing mechani- lly with organic rubbers in most applications at moderate mperatures, but they are unrivalled in many applications here extreme operating conditions prevail.

PROPERTIES OF SILICONE RUBBERS

Silicone rubber is not markedly dissimilar in appearance om other synthetic rubbers when the same pigments and lers are used. When no pigment is added and the filler is lected from certain types of very finely divided silica, highly ansparent rubber of very attractive appearance can be repared. Silicone rubber is exceptionally resistant to xidative degradation, to water, weathering, ozone and orona, but its resistance to chemicals is not outstanding. It unaffected by dilute acids and alkalis, but the polysiloxane chain is readily cleaved by these reagents in concentrated form, and the rubber slowly disintegrates in contact with these. Non-chlorinated aliphatic solvents have little effect, but excessive swelling occurs in chlorinated or aromatic solvents. No permanent deformation results from this swelling when the solvent is removed, however. Table 4 demonstrates the resistance of a general purpose rubber to various chemical reagents and solvents.

Silicone rubbers are usually compounded with some specific application in view, and certain physical properties such as extreme temperature resistance, low compression set, high tear strength, or ease of processing are often developed at the expense of other properties. Table 5 shows the maximum value generally attainable for the principal properties of the fully cured commercial rubbers, though naturally no single rubber is available with all these properties at the maximum level.

Table 5. *Physical properties of silicone rubbers (after curing for* 24 *hours at* 250° *C)*

Tensile strength, lb/in.^{2}	1000
Elongation at break, %	500
Tear strength, lb/in.^{2}	350
Compression set, B.S., %	2·5
Linear shrinkage, %	2
Brittle point, °C	−85
Thermal conductivity, cal/cm^2 × s × °C × cm	7×10^{-4}
Volume resistivity, Ω/cm	10^{16}
Dielectric strength, V/mil at 50% R.H.	800
Power factor (60 c/s)	0·003
Dielectric constant (60 c/s)	9·0

The optimum mechanical properties are, of course, relatively low in comparison with those of organic rubbers at room temperature; properties at room temperature, however, give little indication of performances under service conditions, which may often reach extremes of temperature. The thermal stability of silicone rubbers is such that they undergo no significant change at temperatures at which organic

Table 4. *Chemical properties of silicone rubber, E.*310, 1 *week immersion at* 25° *C*

	Weight % change	*Volume % change*	*Tensile strength % change*	*Elongation % change*	*Hardness (Shore A) % change*
Acids					
Sulphuric 10%	+ 2	+ 2	0	0	− 2
Sulphuric (conc.)			Disintegrates		
Hydrochloric 3%	+ 3	+ 4	0	+10	+ 2
Bases					
Sodium hydroxide 20%	+ 1	+ 2	0	+10	− 4
Sodium hydroxide 1%	+ 5	+ 7	0	0	− 3
Ammonia (conc.)	+ 5	+ 4	−20	−30	+ 8
Ammonia 10%	+ 9	+ 8	−20	−20	− 4
Solvents					
Ethyl alcohol	+ 7	+ 7	−20	+50	−12
Toluene	+120	+160	−50	−30	−16
Petrol	+110	+160	−50	−30	−18
Carbon tetrachloride	+230	+160	−40	−30	−12
Oils					
Castor oil	0	0	0	0	− 6
Linseed oil	+ 1	0	0	+10	0
Mineral oil	+ 8	+ 10	0	+20	− 4
Silicone F. 110/100	+ 35	+ 45	−20	0	−12

rubbers become either very brittle or very soft. At 200° C, for example, almost all organic rubbers become brittle and disintegrate in less than 72 h, whereas the hardness of silicone rubbers rarely rises by more than 10° B.S. and the rubbers remain perfectly flexible. Konkle and others$^{(14)}$ studied the changes in tensile strength and elongation of nine different organic rubbers and silicone rubber at temperatures up to 250° C, and concluded that at temperatures of 150° C and above, silicone rubber was clearly superior to all the organic rubbers tested. The most marked changes occurred in elongation, for whereas the majority of the organic rubbers were embrittled after only a few days at 150° C, the elongation of the silicone rubber had fallen by only half after two weeks and the rubber then appeared to have reached equilibrium. At 250° C all the organic rubbers tested had lost all rubbery characteristics after only four hours, whereas the useful life of the silicone rubber at this temperature was at least three hundred hours. These data do not represent a limiting performance, for silicone rubbers capable of operating at 315° C for up to one week are now available.

The properties of the polysiloxane molecule which cause the pour points of the silicone fluids to be extremely low also result in extremely good low temperature flexibility in the silicone rubbers. Whereas most organic rubbers stiffen below −40° C, standard grades of silicone rubber are flexible up to −55° C, and special low temperature grades are available which are serviceable below −80° C. These latter are based on dimethyl siloxane gums which contain a proportion of phenyl groups in the molecule, and no sacrifice in high temperature stability is therefore involved; the useful temperature span of these silicone rubbers is therefore over 300° C.

The electrical properties of silicone rubbers are equivalent to those of good organic insulating materials at normal operating temperatures, and these properties are not greatly changed when the rubber operates near its temperature limits. Volume resistivity falls only to the order of $10^{12}\ \Omega$/cm at 250° C, for example, and a dielectric strength of about 450 V/mil is not exceptional at the same temperature. Ozone and corona resistance are excellent, and the high water-repellency of the polysiloxane molecule enables resistivity to be maintained even under conditions of extreme humidity. Some care is required in curing silicone rubber if the best possible results are to be obtained; unless curing is carried out at temperatures of 250° C or over, the decomposition products of the curing agent may not be completely volatilized, and the residues may affect electrical properties adversely.

APPLICATIONS OF SILICONE RUBBERS

Silicone rubbers are in general used only in those applications where their special properties make them essential, as their moderate physical properties at room temperature and their relatively high cost do not recommend them for use under normal conditions. Their original application was in military aircraft, where extremes of temperature could be met in rapid succession, and a material which could remain rubbery and flexible at temperatures as low as −50° C and as high as 250° C was of immense value. Since then their use has expanded, and silicone rubbers now find many applications in both commercial and domestic electrical equipment, in sealing devices, and as mouldings and extrusions.

Electrical applications. Much of the silicone rubber manufactured nowadays is used as cable insulation. Compounds are available which can be extruded on standard rubber processing equipment and cured by conventional processes of continuous vulcanization. The insulation is not robust by the standards of other insulants, but it can be protected where necessary and it serves several important purposes. It is not readily degraded if the ambient temperature is high, and thus will continue to function in the event of fire: i flame is actually applied to the insulation it will burn, but its residue is silica, which is itself a non-conductor, so that electrical breakdown does not occur. The conductor itself can be operated at a considerably higher temperature than i possible with organic rubbers, and thus the cross-sectional dimensions of both conductor and insulator can be reduced leading to economies in both materials and space. The good weathering properties and the water repellency of the insulation are essential in exposed positions or where flooding i possible. These considerations are important from the military aspect, and silicone rubber has been extensively used in electrical equipment in aircraft, and in power, control and communication cables in naval vessels. A limited amount of silicone rubber is also used as an extreme temperature insulator in the commercial field.

Non-electrical applications. In many of the uses to which rubber is put, the properties of the rubber in extension—tensile strength, elongation, modulus, tear strength—are of little interest to the designer. In gaskets and sealing devices for example, the important property is compression set, and the best silicone rubbers are now little inferior to organic rubbers in this respect. At extremes of temperature they are of course much superior, and modern service aircraft contain considerable quantities of silicone rubber as bomb-bay door seals, as gaskets in jet engines and as damping media for aircraft engine cooling fans. Silicone rubber can also be coated on heat resistant cloth; in this form it is used in the manufacture of ducting for the conveyance of hot gases and as heat resistant belting (where its release properties are also of interest).

PROPERTIES OF SILICONE RESINS

The silicone resins are based on hydrolysed blends of methyl and phenyl di- and trichlorsilanes, and are always obtained in the form of a solution in an organic solvent—usually toluene or xylene. They are processed in the same way as organic resins, except that curing must be carried out at the operating temperature, which may be as high as 250° C. To avoid blistering and the formation of voids the solvent must be removed slowly, and lengthy curing schedules are often necessary. Silicones resins can in general be cured without the addition of a curing agent, since the resin in solution is a low molecular weight cross-linked polysiloxane containing uncondensed hydroxyl groups, but it is normally advantageous to accelerate the cure after solvent has been removed. The usual additives are metal salts of organic acids of the types used with drying oils.

The resins are used almost exclusively in coating applications, though moulding powders based on resin plus heat resistant filler are available. Films of cured silicone resin are affected by aqueous reagents and organic solvents in much the same way as are silicone rubbers, though precise data are less readily obtained. Physical properties such as tensile strength, flexibility, hardness and processability can be varied considerably by adjusting the proportions of the four chlorsilanes in the hydrolysis blend, but the optimum properties are generally poor compared to those of organic resins at room temperature. As with other silicone products, therefore, the resins find their major applications outside the rmal operating range of equivalent organic products, iefly at high temperatures up to a peak of 250° C. Physical operties can be improved by blending with organic film-rming materials, but this leads to a sacrifice of at least ° C in the upper temperature limit.

Silicone resins find their largest single use as a coating for ass-cloth, and laminates of considerable mechanical strength n be formed by bonding together layers of this material by e application of heat and pressure. The mechanical operties of these laminates depend to a large extent on the pe of glass-cloth used and the treatment it has received uring processing, but even so the best silicone laminates are ot equal in strength to organic laminates at moderate tem-eratures. Electrical properties, however, are little if at all ferior, and the high water-repellency of silicones is an ded attraction in electrical applications. Table 6 shows me of the properties of silicone resin laminates in com-arison to those of organic laminates at room temperature.

Table 6. *Comparison of resin-bonded glass laminates*

	Silicone resin laminate	*Melamine resin laminate*
ensile strength, lb/in.^{2}	15 000–25 000	20 000–30 000
lexural strength, lb/in.^{2}	15 000–25 000	20 000–30 000
ecific gravity	1·9	1·8
ower factor, 1 Mc/s	0·001–0·005	0·05–0·1
lectrics trength, V/mil at 90° C in oil	250–350	150–250
ater absorption (B.S.S. 1137) 1/16 in. %	0·05–0·2	0·2–1·0

Organic resins deteriorate rapidly with increasing tem-erature, however, and few are available which are capable withstanding continuous operation above 130° C. Silicone sins, on the other hand, have an almost indefinite life at 0° C, and can be operated intermittently at temperatures bstantially higher than this.

APPLICATIONS OF SILICONE RESINS

Although they are beginning to be used on a relatively rge scale, the silicone resins have not yet achieved the mmercial importance of silicone fluids and rubbers. One ason for this is perhaps that, unlike the fluids and rubbers, ey must be applied to a substrate, and the necessity of uring at high temperatures to give acceptable physical operties limits the type of substrate that can be used to etals or heat-resistant inorganic materials. In the appli-tions for which they are most fitted their advantages over ganic resins are not perhaps quite so marked as those of e fluids and rubbers over their competitors, but they have vertheless enabled some considerable advances to be made several fields.

ectrical applications. Until the advent of silicones, the nitations in electrical design were to a large extent the nitations of the insulating materials available, notably their or heat resistance. The A.I.E.E. Class B insulators, for ample, which consist of inorganic materials bonded with ganic resins, are rated for continuous operation up to 0° C only. Silicone resins have enabled a new class of ulators to be added (Class H) which are rated for con-uous operation up to 180° C. At this operating tem-rature the life of the conductor becomes as much a factor design as that of the insulator; experience with silicone in insulated electric motors, for example, has shown that the insulation will normally survive several years' operation at temperatures in excess of 180° C, and that ultimate breakdown is more likely to be due to winding failure than to insulation failure. Silicone resins have consequently distinct advantages over organic resins as insulators for conductors which are subject to frequent overload or to a high starting load, or which must operate in high ambient temperatures. As with silicone rubbers, their use also enables considerable economies to be made in the dimensions of electrical equipment, and they are therefore frequently employed in applications where space and weight are important factors.

Laminating resins. As the data of Table 6 illustrates, mechanically strong laminates can be formed by bonding together layers of fabric with resins and these find many structural and electrical applications. Although the properties of the laminates are governed by the properties of the base fabric to an appreciable extent, they are also influenced by the characteristics of the resins. Since silicone resins are superior to organic resins only in their high temperature properties, their electrical properties and their good water-repellency and are much more costly, the laminates have so far been used only for certain specialized functions. Little purpose is served, for example, by applying silicone resins to organic fabrics, where the high temperature stability cannot be fully utilized, and silicone resin laminates are normally based on some form of woven glass fibre. Where the laminate is to be used as an electrical insulating material, any organic size in the glass-cloth must first be removed either by heat treatment at a temperature of about 300° C or by chemical processing. The cloth is impregnated by dipping in a solution of the resin, and this is followed by a short cure; the laminate is formed by bonding together several layers of the impregnated fabric under the influence of heat and pressure. The characteristic silicone properties make these laminates useful materials for the manufacture of slot wedges in motors operating at high temperatures, in electrical panel boards, and in radomes for aircraft.

Protective and decorative coatings. When applied to metal surfaces, silicone resins give good protection in corrosive or moist atmospheres, and their excellent heat stability enables them to be used in many applications where the life of organic coatings would be too short to make their use practicable. When compounded with suitably heat resistant pigments they provide decoration as well as protection under the same severe condition, and are extensively used in paints and enamels for heaters, ovens, exhaust pipes and chimney stacks.

Treatment of masonry. Although the main technical interest in silicone resins lies in their thermal properties, the high degree of water-repellency imparted by silicone resin coatings has also attracted much commercial interest, and they have been found especially effective in the treatment of masonry. When applied in dilute solution—usually only two to five per cent solids content is required—they penetrate the masonry to a depth of about one-tenth of an inch, giving the masonry surface a contact angle with water similar to that of the resins themselves. Pores in the masonry are similarly coated and become hydrophobic, but are not blocked by a continuous film of resin, so that although the masonry becomes impermeable to liquid water it remains permeable to air and water-vapour. This latter is essential for the preservation of the fabric. Treatment with silicones also reduces efflorescence, a condition caused by the extraction of soluble salts usually present in brickwork or concrete.

CONCLUSION

Silicones are playing an increasingly important part in modern industrial development by their ability to function in the form of fluids, rubbers or resinous films at temperatures beyond the range of their organic counterparts. Their progress in certain fields is at present restricted by their mechanical weakness and by their relatively high cost. The former defect will undoubtedly be remedied within limits by the intensive research which is now in progress in many parts of the world. The latter has already responded considerably to the normal pressure of economic growth, and this process is appreciably assisted by the numerous useful and interesting applications which are being found for silicones in the domestic field.

REFERENCES

(1) McGregor, R. R. *Silicones and their Uses*, p. 199. (London: McGraw-Hill Publishing Co. Ltd., 1954).
(2) Rochow, E. G. *An Introduction to the Chemistry of the Silicones*, p. 114 (London: Chapman and Hall Ltd., 1951).
(3) Hunter, M. J., Warrick, E. L., Hyde, J. F., an Currie, C. C. *J. Amer. Chem. Soc.*, **68**, p. 229 (1946).
(4) Fox, H. W., Taylor, P. W., and Zizman, W. A *Industr. Engng Chem.*, **39**, p. 1408 (1947).
(5) McGregor, R. R. *Industr. Engng Chem.*, **46**, p. 232 (1954).
(6) Rochow, E. G. *U.S. Patent* 2,380,995.
(7) McGregor, R. R. *Silicones and their Uses*, p. 4 (London: McGraw-Hill Publishing Co. Ltd., 1954).
(8) Rochow, E. G. *An Introduction to the Chemistry of th Silicones*, p. 133 (London: Chapman and Hall Ltd 1951).
(9) Gainer, G. C. *Industr. Engng Chem.*, **46**, p. 2355 (1954
(10) Polmanteer, K. E., and Hock, R. J. *Rubber Age*, **7** p. 83 (1955).
(11) Warrick, E. L. *Industr. Engng Chem.*, **47**, p. 486 (1955
(12) Blanchard, A. F., and Parkinson, D. *Industr. Engn Chem.*, **44**, p. 799 (1952).
(13) Gessler, A. M., and Rehner, J. *Rubber Age*, **7** p. 875 (1955).
(14) Konkle, G. M., McIntyre, J. T., and Fenner, J. *Rubber Age*, **79**, p. 445 (1956).

ORIGINAL CONTRIBUTIONS

A rhodium-plated kata thermometer for measuring true air velocit

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Rhodium-plated kata thermometers were developed, as rhodium is a more stable coating than silver. The rhodium-plated kata thermometers were tested in non-turbulent air streams at the National Physical Laboratory, Teddington. Formulae for estimating true air velocities from cooling rates of the kata thermometers are given. Accompanying graphs facilitate the calculation of velocities. Cooling of the instruments is not directly related to the square root of air speed at low velocities. From zero speed (still air) up to a velocity of 0·5 m/s, plotting of cooling against velocity results in a parabola, and from 0·5–1·3 m/s in a straight line.

The velocity of air has to be ascertained for determining the volume of air entering or leaving a room when forced ventilation is applied: air speeds are also measured in the estimation of thermal comfort,(1) the pleasantness of a room,(2) its degree of freshness,(3) and strength of draughts.(4)

Low air velocities are determined from the cooling rate of warm bodies, freely suspended in air. The warm bodies, usually taken for this purpose, are the hot-wire anemometer, Hill's kata thermometer,(5) and Yaglou's heated-thermometer anemometer.(6) The hot-wire anemometer as well as the heated-thermometer anemometer are heated by means of an electric current, the strength of which has to be meticulously maintained. It has been pointed out that in a hot-wire anemometer, to be kept at a current of 0·596 A, a variation of only 0·002 A leads to an error of 1% in the determination of speed.(7) The kata thermometer, being a thermometer with a big bulb, does not respond as quickly as the hot-wire anemometer or the heated-thermometer anemometer, but is much simpler in use.

In a fast moving air stream a warm body loses its heat mainly by convection, whereby the degree of heat-los increases with the square root of air speed, and with th excess temperature of the body over the ambient air.(8) Whe air movement is low, as well as in the presence of radiator radiational heat-loss gains in importance.

In the kata thermometer, the correction needed for radia tional gain or loss can be much reduced by silvering its glas surface.(9, 10) Though freshly polished silver has a very lo emissivity (about 0·04–0·06), it is easily scratched an tarnished, whereby this low emissivity is no longer maintaine

Heat-loss from the kata thermometer is related to th root of the air speed only within a certain range of speed There is general agreement that such a law holds good a velocities ranging from one to ten metres per second, bu this does not seem to apply to speeds below one metre.(1 Speeds below 1 m/s are difficult to obtain and to measure Thus many discrepancies reported can be attributed t differences in the fine structure (turbulence) of the approximately steady air streams rather than to errors in measurin the force or wind speed.(12) The purpose of the presen vestigation was to search for a reflecting surface more itable than silver, and to establish the relationship between oling rate of the kata and true air speed at low velocities.

PREPARATION OF REFLECTING KATA THERMOMETERS

Although silvered kata thermometers are available comercially it would be an advantage to have thermometers ated with a reflecting surface which did not tarnish or come scratched easily. We have therefore used rhodium hich is hard and has a low emissivity (0·07), practically the me as highly polished silver. No metal polish for cleansing needed, and, when greasy, the thermometers can be washed ith soap and water. It can be electrolytically deposited on ver. Very good surface mirrors are also obtained by aporation and condensation *in vacuo*. As this method calls r rather elaborate equipment, the job is best left to a maker optical mirrors.

TIMATION OF FACTOR OF KATA THERMOMETER

The factor F denotes the number of milligramcalories, given f by one square centimetre of the kata surface during the itire time of cooling; the cooling rate H is defined as the ımber of milligramcalories dissipated from 1 cm^2 of its ırface per second; whence the cooling rate H equals the ctor F divided by the cooling time (in seconds). The true ılue of the factor can be determined by direct calorimetry(9) water or mercury. By comparing calorimetric values with ıose obtained in still air, various formulae were arrived at, ermitting to find the factor from observations in still air ıly.(9, 13) The factors obtained by different workers did ot agree, and corrections up to 31% were needed in order obtain comparable results.(9) As the kata thermometer o longer is considered an instrument for measuring thermal omfort, but used as a sensitive anemometer, the factor ither may be defined as a constant in calculations of air elocity. Therefore, if the wind speed and the temperature f the ambient air be known, the factor can be calculated.

As we found this is best done at velocities between 1·0 nd 1·8 m/s; for at these speeds the relationship between ooling rate and air velocity is well established, and there is eneral agreement that air velocity enters the calculation ith its square root. The equation of the kata thermometer these speeds is of the form:

$$H = F/\tau = (T - t)(a + b\sqrt{v}),$$

nd solving for F:

$$F = \tau(T - t)(a + b\sqrt{v}),$$

here H is the cooling rate; F is the kata factor; τ is the verage cooling time in seconds; T is the mean temperature, °C, of the cooling range of the kata; t is the air temerature, in °C; a and b are constants depending on the type f instrument used; v is the air velocity, in metres per second.

In the present investigation the kata thermometers had a ooling range from 150–145° F, and from 130–125° F respecvely.* As the emissivity of rhodium is very similar to that f silver, it is permissible to use the constants a and b as ound for silvered katas (Ref. 2, p. 26).

The factor of rhodium-plated katas with a cooling range from 150–145° F therefore is given by:

$$F = \tau(64{\cdot}2 - t)(0{\cdot}0324 + 0{\cdot}5632\sqrt{v}),$$

and by:

$$F = \tau(53{\cdot}0 - t)(0{\cdot}0198 + 0{\cdot}4293\sqrt{v})$$

for the 130–125 °F kata.

This method gives consistent results, as can be seen from the table.

Determination of kata factors from cooling rates obtained at velocities between 1·04–1·78 *m/s*

Air velocity	*Factor for 130–125° F kata*	*Factor for 150–145° F kata*
1·04	435	596
1·28	437	594
1·55	437	597
1·78	431	587

Though it is preferable to determine the factor from readings obtained in moving air, this is not always possible. We therefore determined the cooling times of katas, previously tested in flowing air, in still air, too. In a still air chamber a factor applicable to moving air is found at an air temperature of about 16–17° C from:

$F = 0{\cdot}1792\,\tau\,(64{\cdot}2 - t)$ for the kata with a cooling range 150–145° F,

and, similarly:

$F = 0{\cdot}1751\,\tau\,(53{\cdot}0 - t)$ for the 130–125° F range,

where τ is the average cooling time, and t the temperature of the air. The air temperature in this still air determination of the factor should be between 16 and 17° C; for at temperatures higher or lower than these, the expression $(T - t)$ will enter the formula with a power (Ref. 11, p. 41).

TRUE AIR VELOCITIES FROM RHODIUM-PLATED KATAS

In moving air observations there is no need to introduce a term in $(T - t)^n$, the term $(T - t)$ in its linear form being sufficient (see also foregoing paragraph). With the kata factor known, the cooling rate H is found by dividing the factor by the number of seconds (cooling time, τ). In order to correct the cooling rate H for heat loss due to the temperature of the ambient air, H may be divided by $(T - t)$. Thus $F/\tau(T - t) = H/(T - t)$, usually written: H/θ is a measure of the heat loss due to wind, irrespective of the temperature of the ambient air.

Cooling times of the kata thermometers and air velocities were measured at the National Physical Laboratory, Teddington, in a non-turbulent wind tunnel, supplying horizontal airstreams of known velocities. In this tunnel, air was drawn through a flared inlet, honeycomb and system of gauzes into a cylindrical working section. Downstream of the working section the tunnel reduced to pipes which led to the fan drawing the air through the tunnel.

The calibration of the wind tunnel was in terms of the pressure difference between two points of the narrower section. These pressures were related to velocities previously measured in the working section by a hot-wire anemometer. The anemometer had been calibrated on a small whirling arm. Thus the working section was left clear of other instruments during the tests on the kata thermometers.

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* The metric system is used throughout, except when denoting e kata range, where °F are still in use. The mean temperature T f the 150–145° F kata is taken as 64·2° C, and the mean temerature T of the 130–125° F kata rounded off to 53·0° C.

Fig. 1 shows air velocities plotted against H/θ values, the experimental points entered as hollow circles. In still air we found both kata thermometers to lose heat in a rather similar fashion, H/θ being 0·1751 and 0·1792 for the 130–125° F and for the 150–145° F kata respectively. Up to a velocity of 0·498 m/s the points can be fitted by a curve for either kata. At a speed of 0·498 m/s the curves abruptly change into straight lines, remaining straight up to a velocity of about 1·3 m/s; no sudden change occurs here, for this speed, as well as higher ones (not shown in Fig. 1) can be calculated from formulae with a term in $\sqrt{v}$, as advocated for determining the factor. Consequently, three formulae will be needed for either kata in order to ascertain true air velocities in line with the three parts which form each curve.

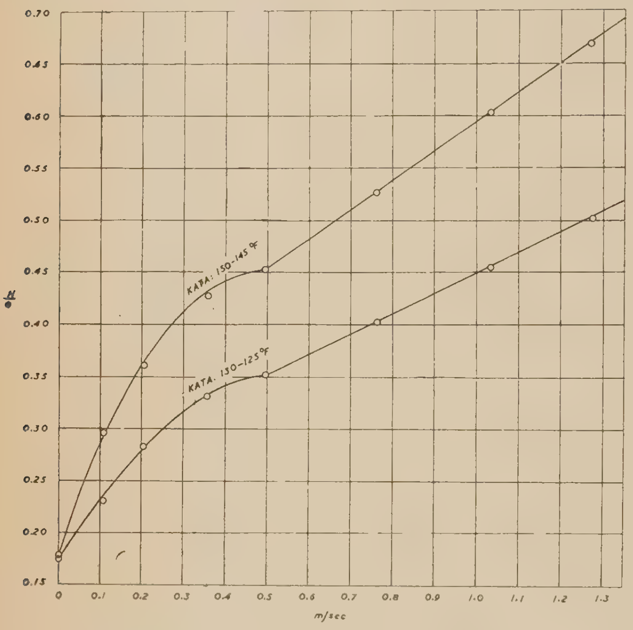

Fig. 1. Cooling of kata thermometer (ordinate) plotted against air velocity (abscissa). Calculated parabola and straight line superimposed on experimental points for either kata

After several trials it was found that a parabola could be fitted to the experimental points, up to a velocity of 0·498 m/s. For the 130–125° F kata the parabola is:

$$V = 0\cdot498 - \frac{[0\cdot3527 - H/(53 - t)]^{0\cdot5933}}{0\cdot7187}$$

Similarly, for the 150–145° F kata:

$$V = 0\cdot498 - \frac{[0\cdot4523 - H/(64\cdot2 - t)]^{0\cdot4757}}{1\cdot080}$$

Between 0·498 m/s and 1·275 m/s straight lines fit the points. For the 130–125° F kata the line is:

$$v = 4\cdot937\, H/(53 - t) - 1\cdot238,$$

and for the 150–145° kata:

$$v = 3\cdot554\, H/(64\cdot2 - t) - 1\cdot110$$

For speeds higher than 1·275 m/s, Bedford's (Ref. 2, p. 26) equations should be used; they are shown earlier in this paper (see under estimation of factor).

It would be rather inconvenient to have to calculate in each case the air velocity from the H/θ value, as three formulae would have to be used, one of them rather complex. At first it was thought to modify the available nomograms as to make them fit the present results, in order to reduce the time needed for calculation. In many instances, however, these nomograms yield sloping intersections, and have to be printed on a large scale as to be accurate. On the other hand, $H/\theta = F/\tau(T - t)$, is quickly calculated and hardly calls for a nomographic solution. Consequently, Fig. 2 shows H/θ values plotted against air velocities on a simple double-scale. The two left-hand scales refer to the 130–125° F kata, the three right-hand scales to the 150–145° F kata.

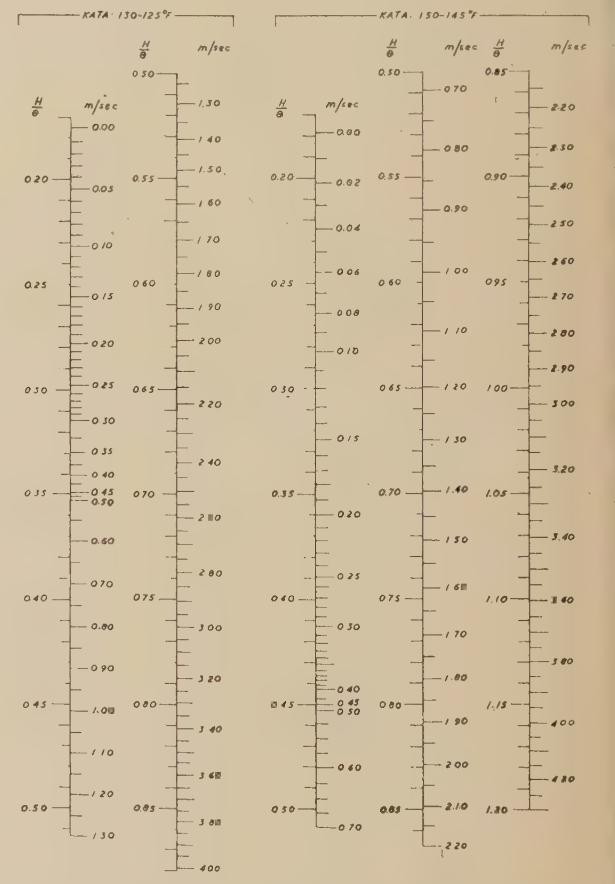

Fig. 2. Cooling of kata against air velocity extended to a speed of about 4 m/s, and drawn on a simple double scale. This extension is based on Bedford's (Ref. 2, p. 26) formulae

DISCUSSION

It has been generally assumed that, as is the case with speeds above one metre, air velocities below one metre can be estimated from formulae employing the square root of velocity. On the other hand, earlier observers have already noted (Ref. 11, p. 47) that formulae based on the square root of velocity fail to give the still-air value. They calculated that the still-air value, when entered into a square root formula, would indicate an air speed of 0·096 m/s which hardly can be ascribed to the buoyancy of the kata.

With increasing air velocity, several types of air flow are be anticipated.(14) In still air an upward stream is due to e kata itself which warms the ambient air. When exposed a horizontal stream of air, this upcurrent is deflected, and th increasing speed, merges with the general flow past the strument. At higher speeds the laminar flow becomes rbulent, with a turbulent wake being formed behind the strument. A further increase in speed renders the laminar r layer, surrounding a rounded body, turbulent even before is layer detaches itself from the body.(15) At the same time e wake becomes smaller, whence the resistance of the body wards air is sharply reduced. In line with these different pes of flow, different formulae for different velocities are to : expected. The speeds at which these changes occur mainly pend on the kinematic viscosity of the air which equals 147 at 15° C, 760 mm; the air speed (cm/s); and a constant. or a cylindrical body its diameter may be taken as the nstant, i.e. 1·8 cm for the kata.(7) The air speed, multiplied the constant, and divided by the kinematic viscosity of the :, is called Reynolds number.

In the present investigation the first noticeable change in e pattern of flow occurred at a wind speed of 49·8 cm/s, ence the Reynolds number R becomes:

$$R = 49{\cdot}8 \times 1{\cdot}8/0{\cdot}147 = 610$$

hile there is a well-defined transition point at a speed of ·8 cm/s, the change from linearity to the square root in e H/θ against v curve is gradual. The shift may be assumed take place at about 130 cm/s, corresponding to a Reynolds ımber of about 1590. Work on hot-wire anemometers(7) es not rule out the possibility that a change in the fashion flow might occur at a Reynolds number in the neighbour- od of 50, corresponding to a speed of about 4 cm/s. nfortunately, this cannot be tested directly, as speeds low 10 cm/s cannot be obtained. As in both parabolae the ints indicating still air, as well as those corresponding to a locity of 10·7 cm/s fit the calculated curve, it is hoped that e interpolation shown in Fig. 1 is justified.

ACKNOWLEDGEMENTS

We are deeply indebted to the late Mr. L. F. G. Simmons for his kind gift of a calibrated hot-wire anemometer, and for his helpful advice. We also want to express our sincerest thanks to Dr. E. Griffiths and the National Physical Laboratory, Teddington, for testing the instruments.

REFERENCES

(1) Houghten, F. C., and Yagloglou, C. P. *Trans Amer. Soc. Heat. Vent. Engrs*, **30**, p. 193 (1924).
(2) Bedford, T. *Basic principles of ventilation and heating*, p. 128 (London: H. K. Lewis and Co. Ltd., 1948).
(3) Bedford, T., and Warner, C. G. *J. Hyg., Camb.*, **36**, p. 498 (1939).
(4) Baetjer, A. M. *Amer. J. Hyg.*, **4**, p. 650 (1924).
(5) Hill, L. (quoted in Ref. 2). *Report on ventilation and the effect of open air and wind on the respiratory metabolism*, 1914. Rep. Loc. Govt. Bd. Publ. Hlth., N.S., No. 100.
(6) Yaglou, C. P. *J. Ind. Hyg.*, **20**, p. 497 (1938).
(7) Simmons, L. F. G. (Personal communication.)
(8) Hill, L., Vernon, H. M., and Hargood-Ash, D. *Proc. Roy. Soc. B*, **93**, p. 198 (1922).
(9) Bedford, T., and Warner, C. G. *J. Hyg., Camb.*, **33**, p. 330 (1933).
(10) Dufton, A. F. *J. Hyg., Camb.*, **33**, p. 349 (1933).
(11) Bradtke, F., and Liese, W.: *Hilfsbuch für raum- und aussenklimatische Messungen (Mit besonderer Berücksichtigung des Katathermometers)*, p. 45–47 (Berlin: Julius Springer, 1937).
(12) International Critical Tables, **1**, p. 402–403 (New York: McGraw Hill Book Company, 1926).
(13) Angus, T. C. *J. Ind. Hyg.*, **6**, p. 20 (1924).
(14) Tietjens, O., and Prandtl, L. *Hydro- und Aeromechanik*, **1**, p. 91 (Berlin: Julius Springer, 1929).
(15) Westphal, W. H. *Physikalisches Wörterbuch*, p. 303 (Berlin: Julius Springer, 1952).

A 20ft Ebert grating spectrograph

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The design and construction of a new high-resolution spectrograph for the visible and ultra-violet regions of the spectrum are described. The optical system is that due to Ebert, in which a plane diffraction grating is used in conjunction with a spherical mirror as collimator and camera. This system has several advantages over conventional concave grating mountings; a stigmatic image is formed and wavelength change is accomplished simply by rotation of the grating. The instrument described can also be used as a spectrophotometer, and can be adapted for use in the vacuum ultra-violet.

order to obtain high spectroscopic resolving power in the sible and ultra-violet regions of the spectrum, it has been stomary in the past to use concave gratings as the diffracting ements. However, now that replica plane gratings of high ality are readily obtainable, excellent resolution can be hieved by using one of these, in conjunction with a concave rror, in the Ebert mounting.

Ebert's original design(1) has been adapted by Fastie(2) in e construction of an infra-red monochromator. The principle is shown in Fig. 1. The slits S_1 and S_2 are within the focal plane of a large concave mirror M and are placed symmetrically about its optic axis, which also passes through the centre of the grating G. Light entering S_1 is reflected as a parallel beam on to the grating by one half of the mirror. Dispersed light of a particular wavelength, depending on the angle of tilt of the grating, is focused on to S_2 by the other half of the mirror. The two off-axis reflections at the mirror largely compensate each other in producing a final image free from significant aberrations.(3)

The advantages of this system compared with other grating mounts have been summarized by Jarrell.(4) In brief, the wavelength transmitted by the Ebert system is changed by rotating the grating about an axis through its centre and parallel to its rulings, a convenient motion for scanning a spectrum photoelectrically, and for changing rapidly from one spectral region to another. The final image is stigmatic, giving high optical speeds. Two separate spectra focused on different parts of the entrance slit are focused on similarly distinct places at the detector, making it easy to record comparison spectra for wavelength calibration. Against this, the two additional reflexions at the mirror surface cause light losses, which are not, however, significant above 2000 Å, and are partly compensated by the gain in optical speed due to the stigmatic image and the high efficiency of a plane grating. The grating can be used at high angles of incidence, but the optical aperture is correspondingly smaller under these conditions.

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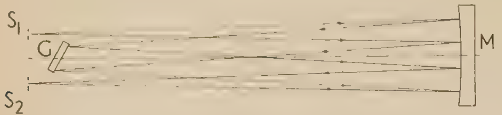

Fig. 1. Optical diagram of Ebert system

DESIGN CONSIDERATIONS

A combined spectrograph and spectrophotometer of the Ebert type has been constructed recently in these laboratories. The initial specifications for this instrument were as follows:

(1) resolution in the visible and ultra-violet regions should be at least $0 \cdot 2\ \mathrm{cm}^{-1}$,
(2) quantitative intensity measurements on spectra should be feasible,
(3) it should be of simple and compact construction, using manufacturers' components where possible, and
(4) provision should be made for evacuating the instrument if necessary, for work in the vacuum ultra-violet region.

It was decided initially that an Ebert system would best fulfil these specifications, although little was known about this type of system at the time, apart from Fastie's work in the infra-red.

The grating chosen was a Bausch and Lomb type 33–53–11–04 replica grating, which had 2160 grooves/mm, and was blazed at 6000 Å in the first order. The observed first order resolving power was +95% of the theoretical value of 160 000. The ultra-violet down to 1500 Å could be covered in the first three orders, thus simplifying the problem of separating overlapping orders. The grating was mounted with its rulings vertical and at right angles to the optic axis of the spectrograph, and could rotate about a vertical axis through its centre. The ruled area was 65 mm high by 76 mm wide, on a rectangular blank 76 by 85 mm.

Two independent optical paths within the instrument were used. One path, shown in plan in Fig. 1, was used when scanning a spectrum photoelectrically. The slits S_1 and S_2 were mounted vertically with their centres at the same height as the centre of the grating. A photomultiplier covered the exit slit S_2. The other path was used when photographing a spectrum, with the grating at a fixed angle. A third vertical slit was mounted vertically beneath the optic axis, so that entering light passed immediately beneath the grating to fall on the lower half of the mirror. After diffraction by the grating and reflexion in the upper half of the mirror, light rays returned over the top of the grating to form a spectrum dispersed horizontally in the focal plane of the mirror.

The separation dl at the photographic plate which the grating will just resolve is given by

$$dl = f\lambda = 2F \tan \beta / R \qquad (1$$

where f is the numerical aperture of the spectrograph at grating angle $\beta = \sin^{-1}(n\lambda/2d)$, n being the order and d the grating constant; F is the focal length of the mirror and R the resolving power in the nth order. F must be sufficiently large for lines a distance dl apart on the plate to be distinguishable. The resolving power of photographic emulsions varies over a wide range. However, 100 lines/mm was taken as a practical upper limit for this, and this estimate proved satisfactory. Hence it was necessary that dl should exceed $0 \cdot 01$ mm at all wavelengths and orders in which the spectrograph was to be used. From equation (1), a suitable focal length was 20 ft. Fig. 2 shows the separation dl for the given grating used with a mirror of this focal length. It can be seen that $dl > 0 \cdot 01$ mm at all wavelengths above 1500 Å.

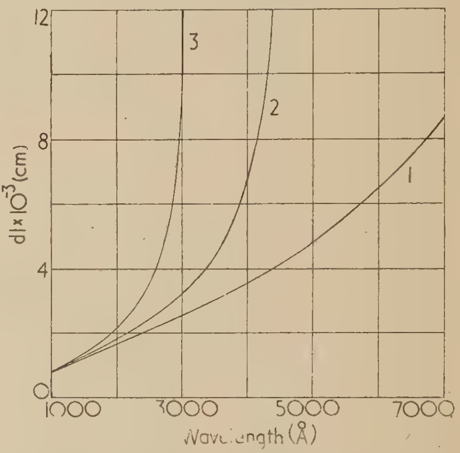

Fig. 2. Least separation of resolvable lines at the photographic plate for the instrument described

A standard concave spherical Schlieren mirror, with surface correct to $\lambda/8$ of mercury green light, was employed. Its diameter was 12 in. Now this dimension depends on two factors; the separation of the slits and photographic plate from the spectrograph axis, and the length of spectrum to be photographed on one plate. The slit-axis separation is least and the necessary diameter of the spectrograph as a whole is a minimum, when the grating is placed as close as possible to the plane of the slits and the cones of light to and from these and the plate just graze the edges of the grating. For this reason, a rectangular grating blank is preferable to a circular one. In practice, it is more convenient to mount the grating slightly within the focal plane of the mirror, and to locate the

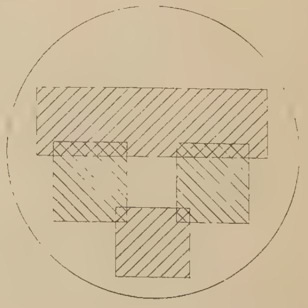

Fig. 3. Mirror areas used to reflect light

ts and plate slightly further off the axis. The necessary irror size is easily found by graphical construction since, to good approximation, requisite light from a point in the cal plane is projected on to the mirror as a rectangle equal size and shape to the grating and with this point as its ntre. In the present case, the centres of the three slits were ch 2½ in. from the optic axis, and the plate was 6½ in. long; 12-in. diameter mirror provided sufficient reflecting area if ; centre was offset by 1¼ in. above the spectrograph axis. ıe area used is shown in Fig. 3.

CONSTRUCTIONAL DETAILS

The main body of the spectrograph (*A* in Fig. 4) consisted 12 by ⅜ in. high pressure steel tubing. This provided a gid construction, and was suitable for evacuation of the strument. Near the centre of the tube, a flange (not shown) as provided for attaching a 12 in. diffusion pump.

A cylindrical box *B* was bolted to one end of the tube. his contained the mirror mount. The mirror, 2 in. thick, ted into a cast brass pan *C*. This was supported at either de by crossed steel strips, which were attached to vertical ms mounted on a circular base plate *D*. These flexible rips enabled the mirror to be tilted about a horizontal axis. he base plate was supported on three symmetrically placed ıll bearings which ran in a circular groove in a lower plate *E*, ırming a three point support which enabled the mirror to be ɔtated about a vertical axis. This lower plate was bolted in ırn to a lathe cross-slide *F*, which provided a motion for ɔcusing. All mirror movements were controlled by vernier rew threads.

The three slits and the plateholder were mounted on a rcular plate *G* fitting over the other end of the tube. The ateholder *H* took plates 6½ by 1½ in., a size which could be ısily adapted to take strips of 35 mm film. The lower slit *J* ɔr photographic work was Adam Hilger's type F.1386, and ıe two side slits *K* were type F.111. All three slits could be ɔtated in the focal plane about their centres for alignment ırposes, and the side slits were mounted in tubes that could ꜫ moved parallel to the spectrograph axis.

The grating was mounted in a brass box *L*, lined with rips of lead foil, a curved spring of phosphor-bronze applyıg a light retaining pressure on one side. This box was ıounted on two short triangular pillars, with a space between ıem to enable light to reach the mirror from the lower slit. hese were fixed to a turntable *M* on a three point adjustable mount, with long screws which reached below the grating casing and which were accessible from outside when the cover *N* was removed.

The grating turntable was driven by a reversible 1500 rev/min synchronous motor *O*, through a pair of spur gears *P* and three successive worm reduction gears *Q*, *R* and *S*. The grating rotated at about 1 rev/h when scanning spectra; a range of speeds was obtainable by changing the spur gears. A high-speed drive was also provided in order to move rapidly from one spectral region to another. This entailed mounting the motor on a platform which could rock through a small angle: in one extreme position, the worm drive *Q* was engaged, and in the other extreme position this worm was disengaged and the skew gears *T* engaged, driving the worm wheel *Q* at motor speed. The platform was rocked by a solenoid, the motion being damped by an oil dashpot, and the gears fitted with brakes to prevent them "crashing" (these are not shown). The revolution counter *U* remained permanently geared to the grating turntable, and was calibrated to indicate the approximate wavelength setting of the instrument. The grating assembly and drive were supported by three pillars *V*, enabling them to be enclosed in the vacuum-tight cover *N*.

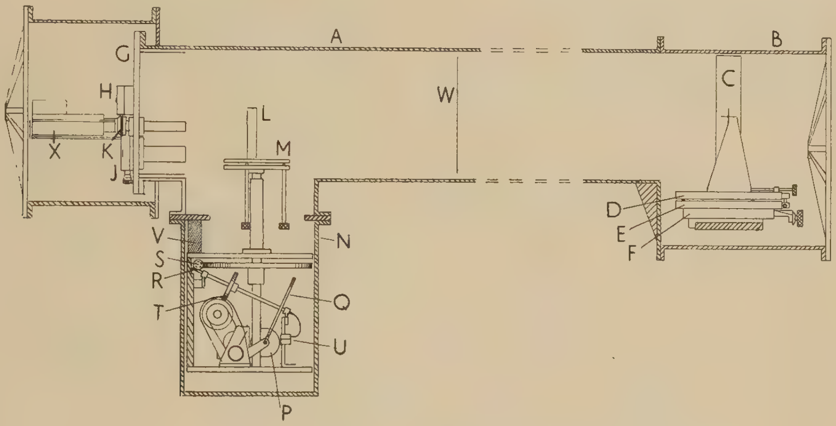

Fig. 4. Sectional view of spectrograph

Because of the long optical paths within the instrument, it was essential that it should be free from mechanical vibration and any variation in temperature. It was located in a windowless room 20 ft below ground level and supported on three pillars, each consisting of massive slabs of concrete interleaved with sheets of cork and surmounted by a large rubber anti-vibration mounting. The room was thermostated to 20 ± 0·1° C. Temperature changes of this magnitude over a period of days for the spectrograph as a whole could be tolerated: but small differential temperature changes between parts of the instrument during use had to be minimized carefully. For example, a change of relative temperature of 10^{-4} °C between the sides of the tube along its length would displace an image at 2500 Å in the second order by a distance equal to *dl*, and hence curtail resolution. Such shifts were prevented by covering the entire tube with 3 in. thick glass-wool insulation. These arrangements proved satisfactory for exposures of many hours' duration.

ELIMINATION OF STRAY LIGHT

It is apparent from Fig. 1 that light rays from S_1 can be directly reflected at the centre of the mirror on to S_2. Such rays were the principal source of stray light. To eliminate them, a baffle cut from thin metal sheet was placed crossways in the tube at W in Fig. 4, 2½ ft from the slits. Fig. 5 shows a plan of this baffle. Light entering the lower slit passed directly beneath the edge X, which intercepted those rays directed towards the centre of the mirror. It was possible to use a slit height of 5 mm without occluding any of the mirror area needed to reflect incoming light from the slit on to the grating. The edge Y served a similar function during photometric use.

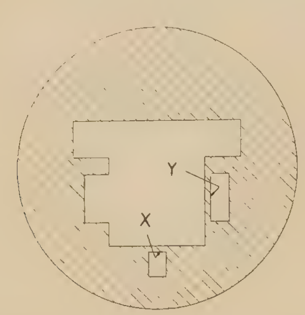

Fig. 5. The light baffle

In addition, stops were fitted over the inner ends of the tubes on which the entrance slits were mounted, to limit light beams to approximately the correct maximum aperture. It was also found advantageous to stop down incident light externally to this aperture.

PHOTOGRAPHIC USE

The entrance slit was always set at a width equal to dl. At high angle settings of the grating, it was necessary to rotate this slit by a small angle about its centre to compensate for the tilt of the spectral lines at the plate.(4) Down to 2500 Å, discrimination between overlapping first and second order spectra was achieved simply by the use of appropriately sensitized plates and external glass filters. Owing to the flatness of the focal plane of the instrument, it was not necessary to bend the plate in its holder. No loss of resolution due to optical aberrations was found in spectra recorded near the ends of the plate. Using a high-pressure xenon arc light source, exposures of the order of one hour were common. Resolving powers of up to 150 000 × n we obtainable experimentally. This is illustrated by Fig. which shows the hyperfine structure of the 2537 Å mercu line, taken in the second order.(5) The two dark central line which are clearly resolved, are components whose separatio is 0·0115 Å.

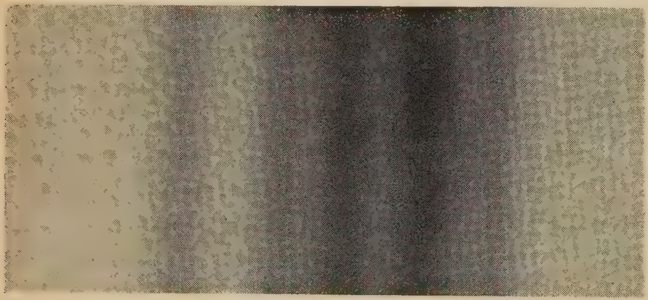

Fig. 6. Hyperfine structure of the mercury 2537 Å line in emission. Taken in the second order

PHOTOMETRIC USE

Incoming light was chopped at a point close to the sourc at 650 c/s by a rotating sector disk driven by a synchronou motor. A thirteen stage photomultiplier (X in Fig. 4) wit a quartz window was mounted over the exit slit. Alongsid it was mounted the potential divider which supplied th dynode voltages, connected across a stabilized 2000 V suppl The a.c. signal generated in the photomultiplier was limite to 2 μA to ensure linearity of output. This signal was fe to an amplifier with a flat-topped response curve over th range 650 ± 10 c/s, and with a maximum gain of 2 × 10 capable of being attenuated in 2 : 1 steps.(6) The rectifie output from this was fed into a Brown potentiometri recorder. A contact maker attached to the grating driv enabled wavelength calibration marks to be made on th recorder chart. All power supplies were stabilized, and a operations controlled by a panel of twelve switches. Fo further details of similar apparatus, see King.(7)

Owing to slight vibration from the motor driving the gratin being transmitted to the optical elements, the apparent resolving power was reduced to about 60 000 × n. The highes resolving powers could only be achieved photographically with the grating stationary.

To obtain maximum response, the entrance and exit slit could be used at their full height of 20 mm; the use of such straight slits at the apertures employed did not affect resolving power.(3)

ACKNOWLEDGEMENTS

It is a pleasure to thank Prof. C. K. Ingold for his support and interest in this project. Much of the constructional work was carried out in the workshops of the Engineering Department of this College, under the direction of Prof. B. J. Lloyd-Evans. The detailed design of mechanical parts was largely due to Mr. F. W. Kent of the latter Department.

REFERENCES

(1) Ebert, H. *Wied. Ann.*, **38**, p. 489 (1889).
(2) Fastie, W. G. *J. Opt. Soc. Am.*, **42**, p. 641 (1952).
(3) Fastie, W. G. *J. Opt. Soc. Am.*, **42**, p. 647 (1952).
(4) Jarrell, R. F. *J. Opt. Soc. Am.*, **45**, p. 259 (1955).
(5) Further illustrations in King, G. W. *J. Chem. Soc* (to be published).
(6) Brown, D. A. H. *J. Sci. Instrum.*, **29**, p. 292 (1952).
(7) King, G. W. *Bull. Photoelect. Spect. Group*, **9**, p. 22 (1956).

orrection due to aperture in transmission interference microscopes

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The fringe spacing in transmission interference microscopes is shown to require a correction due to the oblique rays, with respect to the ordinary value valid for perpendicular rays. The spacing, and accordingly the measured path differences, $t(n_x - n_0)$, are smaller than the normal values (opposite to the case of reflexion microscopes). Calculations are made for different values of condenser N.A. and varied parameters, showing corrections up to −15%. The fringe intensities also decrease with the order of interference when it is low. Experiments confirm these findings. The effect is discussed in relation to some general ideas of (x, y)-fidelity and (z)-fidelity as obtained in a limited optical information channel.

ring the rapid growth of applications in interference roscopy, the need for consideration of high-aperture cts on the results has mostly been neglected. Accuracies up to $\lambda/300$ in optical paths are often spoken of, and tometric circumstances are considered to be the main or which limits this accuracy.

n earlier literature, such effects were considered,(1) and ntly Tolmon and Wood,(2) Gates,(3) and Bruce and rnton(4) have treated the reflexion interference micropes from this point of view. We found a discrepancy ween the results from different transmission interference roscopes, which necessitated an investigation. It is true t the mathematics will be more complicated in this case, e refractive indices enter as parameters. We have also ulated somewhat differently from the authors just ted,(3, 4) and also from Davies and Deeley(5) who have ted the matter theoretically for a Dyson microscope. erence should especially be made to an interesting treatnt of interferences in wedges made by Schulz,(6) also ling to fringe spacing corrections and "modulation" of fringe intensities.

THEORETICAL TREATMENT

Ve assume an interference microscope with an illuminating em of a N.A. $= n_0 \sin v$. The objective may have contional high aperture, but for this question the condenser . plays the most important role. For the calculations, presumption is made that the whole condenser aperture lled with monochromatic light and that its amplitude and nsity is independent of the angle within this cone; all the ics should be ideal. Critical illumination is assumed, ough we know that neither this nor the Köhler type is ctly realized. The object is a planoparallel film of thicks t and refractive index n_x; the immersion fluid, or, more eral, the contents of the part of the microscope which as reference space, has the refractive index of n_0.

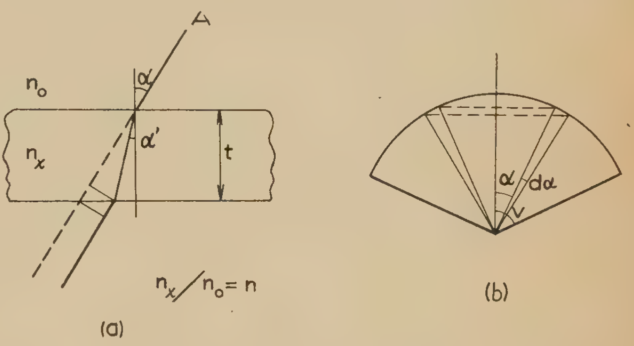
Vith these assumptions, the optical path difference Δ due a beam of light from A making the angle α with the axis hin the reference field, and α' within the film to be measured asily found to be [Fig. 1(*a*)]

$$\Delta = n_0 t(n \cos \alpha' - \cos \alpha) \qquad (1)$$

ere we have introduced the relative refractive index n_x/n_0 (here always supposed to be larger than unity). f we calculate with completely coherent light, the addition he amplitudes within the conical shells [Fig. 1(*b*)] gives

$$A = \int_0^v \exp\left[ikn_0 t(n \cos \alpha' - \cos \alpha)\right] \sin \alpha \, d\alpha \qquad (2)$$

where $k = 2\pi/\lambda$. Obviously, no analytic solution is known for this integral, although in special cases it can be expressed as Weber–Lommel functions. The straightforward calculation method is to trace the complex amplitudes for sufficiently small domains of the angle in a diagram and determine values of amplitudes and phases in this way.(7) However, it should be nearer the truth to assume that the light from each conical shell is incoherent with that from the others, and in this case the intensity functions, if we assume that zero order gives constructive interference, are obtained as



(a)
(b)

Fig. 1. For calculation of retardations at oblique incidence, see the text

$$I(t, v) = \frac{\int_0^v \cos^2\left[kn_0 t(n \cos \alpha' - \cos \alpha)\right] \sin \alpha \, d\alpha}{\int_0^v \sin \alpha \, d\alpha} \qquad (3)$$

This intensity function of thickness and condenser half aperture angle v must be calculated separately for each parameter pair (n_0, n). Numerical evaluation was made for $n_0 = 1$, $n = 1{\cdot}5$, which corresponds to test glasses dealt with below, and the results are given in Fig. 2 for the first orders of interference. The results deviate a little but not much for the case $n_0 = 1{\cdot}34$, $n = 1{\cdot}01$ and $1{\cdot}05$ as is obvious from Fig. 3. This case was of interest to us in a work on haemolysis of blood cells.(8) We have the two expected deviations from the $\cos^2$ curves valid for zero condenser aperture: first, the averaging over the angles imply that maxima and minima have intensities other than 1 and 0 respectively, second, that the fringe spacing is less than λ. The first effect can be interpreted as decreased coherence originating from an out-of-focus displacement between the test and comparison beams. The second effect implies a correction which has the opposite sign from that valid for reflexion microscopes(2, 3, 4) or in other cases[(6)] due to the fact that our path difference for oblique rays, equation (1), is larger than that for perpendicular, while $t \cos \alpha$ for the reflexion case is less than t.

For the small number of interference orders of interest in this type of interference microscopes, the deviation from the value for normal rays is sufficiently close to being proportional to t as to allow a percentage correction, as in Fig. 4. It is, however, obvious from equation (3) that this is not true for higher orders.[(4)] Evidently the corrections are considerable compared to the accuracy easily accessible with these instruments. Calculations from equation (2) give results which are not too far from those obtained from equation (3).

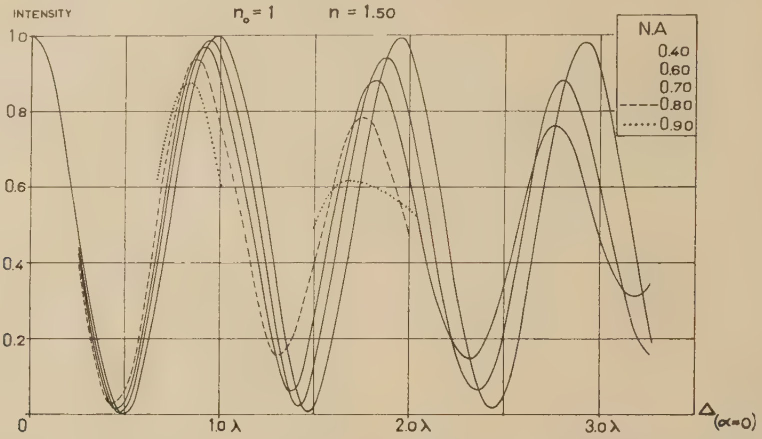


Fig. 2. Numerical evaluation of equation (3), giving the intensity function of interference fringes for different numerical apertures. The horizontal scale gives real optical path differences as measured with zero numerical aperture

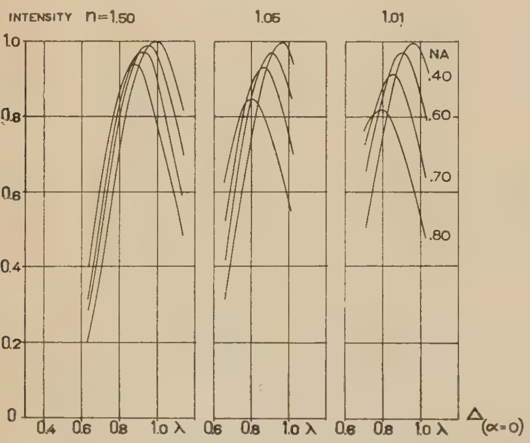


Fig. 3. The intensity function for an optical path difference of around one wavelength calculated for the relative refractive index of 1·50, 1·05, and 1·01

EXPERIMENTAL TESTS

For checking the accuracy of optical thickness measurements in different interference microscopes we used ordinary microscope slides which were etched down except for one narrow strip.

We have measured such a specimen with two narrow-aperture microscopes (1 and 2) and with two wide-angle microscopes (3 and 4). (1) The geometrical thickness (t) was measured with multiple-beam interferences in transmission. For this purpose we used the C. E. Johansson microscope "Multimi"[(9)] (140 × total magnification). T values found were 4000 Å before measurements (2), (3) a (4) and 3980 Å afterwards (max. error 20 Å). The optic path difference of the ridge ($n = 1 \cdot 5194$ for $\lambda = 5461$ Å) air is thus 2070 Å (max. error 10 Å). (2) The optical thic ness was measured with a modification of the Franc eyepiece which one of the present authors[(10, 11, 12)] has mad The condenser light source is in this case slit-shaped a itself acts as the aperture stop, giving practically ze numerical aperture. The field was not kept phase-even, usual, but filled with monochromatic fringes (5461 Å), a the displacement of a fringe within the over-lapping regio was photographed and scanned with a microphotometer (s Fig. 5). The overlapping part was placed between differe fringes, and the result from five measurements was 204 2090, 2085, 2125, and 2085, or on the average 2085 Å.

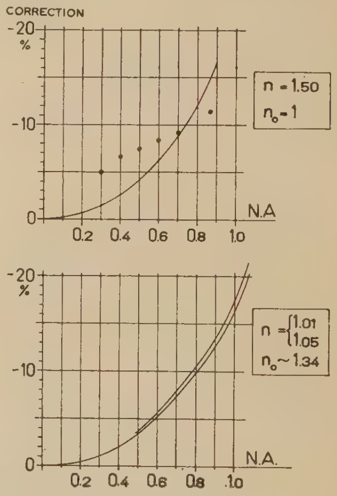


Fig. 4. The curves are calculated corrections for different numerical apertures. In the upper figure the experimental values found with the Dyson microscope are plotted

The two microscopes with wide-angle condenser apertu are those of (3) Dyson[(13)] and (4) F. H. Smith.[(14)] With th Dyson microscope, it was possible to vary the effecti condenser aperture by the substage iris. With the 40 × obje which we used it was possible to realize a numerical rture of maximum 0·87. In order to have the best uracy, the fringes were photographically recorded and nned with a microphotometer as in (2). It appeared that values obtained with this microscope were higher than se from (1) and (2). In the upper part of Fig. 4 the points w the position of the excess over the values from the asurements (1) and (2). The trend is obvious, although

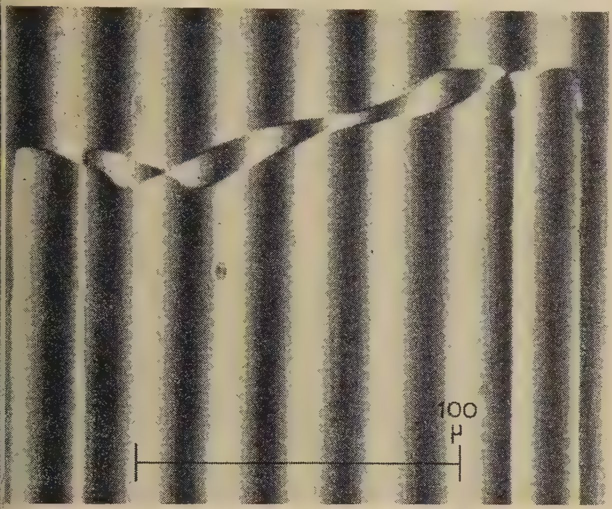


Fig. 5. A photograph from experiment (2), showing the louble images of the test object crossed with interference ringes. The displacement of the fringes occurs in the three areas where the double images do not overlap

do not have good agreement with the theoretical curve ich is only slightly affected by the central obstruction. The ference is due mainly to the lack of realization of our eoretical assumptions. The errors in the measurement ly one or two fringes could be obtained in the field of w) are estimated to ±2%.

For the Smith microscope, we have often been troubled by e effect that Dyson[15] has pointed out, namely, that a ost image from other parts of the field may be superimposed the image of the object and falsify the results. Measurents were made on the same test object at the Institute Physiology in Uppsala by Mr. Zade-Oppen with the mpensation half-shade eyepiece. The values were spread om 2000 Å to 2200 Å. In one series only, a significant nd of values increasing with the aperture could be found.

Even though an interference microscope is "self-calibrating," is advisable to have standards of optical paths to calibrate e scale for a certain aperture and illuminating system, if termost precision is required.

RESOLUTION AND OPTICAL PATH ACCURACY

The aim of working with high condenser apertures even in erference microscopes is to obtain good resolution. But can ask quite generally, if it is possible to retain all the leways information which is connected with resolution, d at the same time let the instrument work in another way, mely, to convey information about the third dimension, , about optical paths. Blanc–Lapierre[16] and others ve shown that the information capacity of an optical annel (a certain aperture of condenser and objective) is hausted by resolving points of a certain density in the (x, y)-plane, it acts as a spatial frequency cut-off filter. One of the present authors[17] has pointed out, especially for multiple-beam interferences, that one must pay for this additional (z) information by giving up some of the mapping (x, y) accuracy.

We feel that this example belongs to the same class. It is quite true that resolution, in the classical sense, is reduced with the condenser aperture, which we will now call α_C. We recall that the objective aperture (α_O) which has most influence on the image quality is retained also in the types of interference microscopes that we deal with. The resolution limit for x (or y) is[18]

$$\Delta x = \frac{\lambda \,.\, K(\alpha_C)}{\alpha_O} \qquad (4)$$

In this relation, the function $K(\alpha_C)$ varies slowly with α_C, being 0·85 for $\alpha_C = 0$ and 0·60 for $\alpha_C = \alpha_O$.[18]

It is not always possible to calculate the correction for wide-angle condensers, as it is also dependent on the shape of the object. Especially we find that at a sharp phase-border, where the "mapping accuracy" (resolution) should be ideal, the aperture cones intersect the border so as to make the phase undetermined in a region which is often much larger than the classical resolving limit.

For narrow-aperture condensers, on the other side, no corrections of the optical path differences enter. These types of microscopes should therefore be preferred when phase-even objects are concerned, as thin films, steps, etc., Even for objects of size or structure near the resolving limit, they may also in some cases be used with not much less ability to resolve than the wide-angle microscopes. For some types of birefringence interference microscopes,[10] the reduction in resolution only appears perpendicular to the slit-shaped aperture, since the aperture is larger in the slit direction.

REFERENCES

(1) Kinder, W. *Zeiss-Nachrichten*, p. 91 (1937).

(2) Tolmon, F. R., and Wood, J. G. *J. Sci. Instrum.*, **33**, p. 236 (1956).

(3) Gates, J. W. *J. Sci. Instrum.*, **33**, p. 507 (1956).

(4) Bruce, C. F., and Thornton, B. S. *J. Sci. Instrum.*, **34**, p. 203 (1957).

(5) Davies, H. G., and Deeley, E. M. *Exper. Cell Research*, **11**, p. 169 (1956).

(6) Schulz, G. *Annalen d. Phys.* (6), **14**, p. 177 (1954).

(7) Ingelstam, E. *Exper. Cell Research*, Suppl. 4, p. 150 (1957).

(8) Marsden, N., Zade-Oppen, M., and Johansson, L. P. *Exper. Cell Research*, **13**, p. 177 (1957).

(9) Pamphlet issued by C. E. Johansson, Eskilstuna, Sweden.

(10) Johansson, L. P., and Afzelius, B. M. *Nature* [*London*], **178**, p. 137 (1956).

(11) Ingelstam, E. *J. Opt. Soc. Amer.*, **47**, p. 536 (1957).

(12) Johansson, L. P. *Exper. Cell Research*, Suppl. 4, p. 158 (1957).

(13) See pamphlets from Cooke, Troughton and Simms Ltd., York, with references to original papers.

(14) See pamphlets from Baker and Co., London, with further references.

(15) Dyson, J. *J. Opt. Soc. Amer.*, **47**, p. 557 (1957).

(16) Blanc-Lapierre, A. *Annales de l'Institut Henri Poincaré*, **13**, p. 245 (1953).

(17) Ingelstam, E. *Arkiv Fysik*, **7**, p. 309 (1953).

(18) Hopkins, H. H. *J. Opt. Soc. Amer.*, **47**, p. 508 (1957).

A total-absorption Čerenkov counter for photons of about 100 MeV energy

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The counter uses a cylindrical crystal of thallous chloride 12 cm long and 9·3 cm in diameter viewed by a photomultiplier tube, and is capable of giving pulses of up to 3 V in height without serious departure from linearity. The pulse height resolution for 78 MeV photons is 34%, and both the mean pulse height and resolution remain constant to within 5% over an entrance aperture 5 cm in diameter. The performance of the counter is discussed in some detail, and it appears that the resolution is limited principally by strong absorption of ultra-violet light in the crystal.

Much work has been done in recent years on the development of total-absorption scintillation(1, 2) and Čerenkov counters,(2–6) in which a high-energy photon produces a cascade shower in a suitable absorber, and is detected by means of either luminescence or Čerenkov radiation from the electrons of the shower. Since scintillators have in general low density and stopping power, very large absorbers are required to contain cascade showers produced by high-energy photons, whereas a variety of transparent materials of high stopping power may be used as absorbers in Čerenkov counters, and for a given photon energy such a counter may be made more compact than a scintillation counter.

A defect of this type of counter is that its light output is very small. The energy dE radiated in the frequency interval $d\nu$ by a particle of charge e e.s.u. moving a distance dx in a medium of refractive index n with a velocity v greater than c/n, and the angle θ between the direction of emission of light and the direction of motion of the particle, are given by the equations(7)

$$dE = 4\pi^2(e^2/c^2)(1 - 1/\beta^2 n^2)\nu d\nu dx \qquad (1)$$

$$\cos\theta = 1/\beta n \qquad (2)$$

where $\beta = v/c$

A thallous chloride crystal of refractive index 2·2 is used in the counter to be described, and integration of equation (1) shows that the energy radiated in the wavelength range 3000 to 6000 Å by a relativistic electron is about 2 keV/cm. The collision energy loss for a relativistic electron in thallous chloride is about 10 MeV/cm, so that only about 0·02% of the energy absorbed is converted to useful light, whereas the conversion efficiencies of scintillators for electrons are of the order of several per cent. Since the light output in Čerenkov counters is very low, the principal cause of loss of energy resolution is statistical fluctuation in the number of electrons emitted from the cathode of the photomultiplier tube, and it is therefore necessary to collect the greatest possible fraction of the light emitted in the absorber.

THALLOUS CHLORIDE CRYSTAL AND COUNTER

The crystal was grown from a liquid melt, and was cylindrical in shape with a conical end, half of which was sawn off to facilitate mounting of the crystal in the counter. The final length of the crystal was 12·0 cm, and the diameter of the cylindrical portion 9·3 cm. The specific gravity of the crystal was 7·0, and its refractive index was 2·2. In transmitted light it appeared to be a little cloudy, and to have a very faint yellow tint. The spectral absorption of the crystal was measured with a set of approximately monochromatic filters, and the results are given in the table. The crystal is practical opaque to ultra-violet light, and shows marked absorptio at the violet end of the visible spectrum.

Optical transmission characteristics of thallous chloride crystal

Filter	*Approximate wavelength (Å)*	*Transmission factor for 12 cm thallous chloride*	*Absorption coefficient (cm—1)*
Wood's glass	3650	0	—
Violet	4100	0·66	0·034
Blue	4400	0·76	0·023
Green	5200	0·88	0·011
Orange-yellow	5900	0·94	0·005

The construction of the counter is shown in Fig. 1. A 4½ in. diameter type 6099 eleven-stage photomultiplier (b E.M.I. Ltd.), with a stated cathode sensitivity of 40 µA/i was used as light detector. Optical contact between surface was made with a mixture of liquid paraffin and white Vaseline and the surface of the crystal was painted with a titanium oxide paint in order to improve light collection.

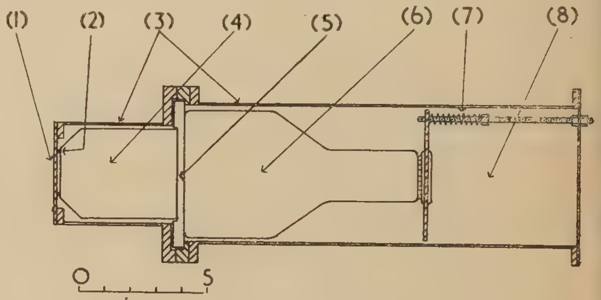

Fig. 1.—Diagram of the Čerenkov counter

(1) 3/32 in brass entrance window; (2) compressed rubber O-ring; (3) brass containers for crystal and photomultiplier tube; (4) thallous chloride crystal; (5) Perspex plate; (6) E.M.I. type 6099 photomultiplier tube; (7) compression spring (one of three); (8) space occupied by dynode resistance ladder and cathode follower.

MEASUREMENT OF PERFORMANCE

The performance of the counter was studied using the continuous X-ray beam of the Oxford 125 MeV synchrotron Pulses from the counter corresponding to incident photons in a small range of energies were identified by means of a "monochromator" identical in principle with an instrument cribed by Weil and McDaniel.(8) A scintillation counter s placed in such a position as to intercept the orbits of raded electrons which, in passing through the internal get of the synchrotron, had radiated photons of energy ıal to 70% of the peak energy of the circulating electrons. output from a coincidence circuit with a resolving time 5 m μs, fed with pulses from both the scintillation and enkov counters, was used to open a gate through which Čerenkov counter pulses were passed before analysis by wenty-five-channel kicksorter.

a) *Linearity of output.* According to data supplied by manufacturers the relation between illumination and ode current for the type 6099 photomultiplier tube departs m linearity by about 10% at an anode current of 10 mA. h an anode current would correspond to a pulse height 5 V assuming a spread in transit times of 10^{-8} s and a al anode capacity of 20 pF. It was found that pulses of to 15 V in height could be obtained with 100 MeV photons hout exceeding the recommended maximum anode voltage, it was expected that the output of the counter would be ited by the necessity for a linear response rather than by available gain of the photomultiplier tube. The mean se height from the counter was measured at mean photon rgies of 78, 60 and 42 MeV, corresponding to synchrotron k energies of 110, 84 and 59 MeV respectively, with an de voltage of 1890 V. Serious non-linearity was observed, d was much reduced by modifying the dynode resistance in to give larger voltage differences on the last three stages n on the preceding ones.

Curves then obtained for the variation of mean pulse height h photon energy are given in Fig. 2, for anode voltages 1890 V and 1650 V. The response of the counter was nost linear up to an output of 3 V from the photomultiplier, d in all subsequent measurements the output pulse amplitude s kept below this value by working at a reduced anode ltage.

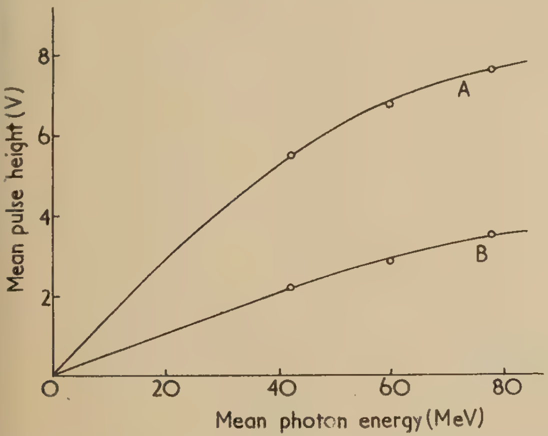

Fig. 2.—Variation in mean pulse height from counter with mean energy of photons selected by the monochromator

Curve *A*, photomultiplier anode voltage 1890 V; curve *B*, 1650 V.

(b) *Pulse height distribution.* Fig. 3 shows the pulse height stribution obtained with photons of mean energy 78 MeV. e mean pulse height was 21·7 and the full width of the stribution at half height was 7·4, the units being channel dths of the kicksorter, giving a resolution of 34%. Because the spread of energies of the photons from the monochromator, the value was greater than the intrinsic resolution of the counter but, as will be seen from the theoretical estimate of resolution in the next section, the difference was probably very small.

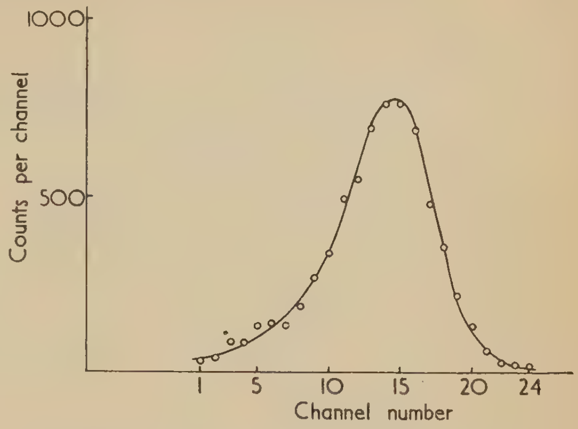

Fig. 3.—Pulse height distribution obtained with the multichannel kicksorter and monochromator for photons of mean energy 78 MeV

(c) *Effective aperture.* Pulse height distributions for 78 MeV photons were obtained, using the monochromator and twenty-five-channel kicksorter, with narrow collimated beams entering the counter parallel to the crystal axis along the axis and at distances of 2 and 4 cm from it. The relative mean pulse heights for the three cases were 100, 98 and 86, while any change in resolution was too small to be observed. It appeared that the counter could be used with an aperture of about 2·5 cm radius without introducing a loss of more than 5% in mean pulse height at the edges.

THEORETICAL ESTIMATE OF PERFORMANCE

In order to assess the performance obtained with the counter in practice, an attempt was made to calculate the pulse height and resolution to be expected.

(a) *Pulse height.* Taking the radiation length and critical energy of thallous chloride as 0·94 cm and 8·3 MeV respectively, and using the data of Kantz and Hofstadter,(2) the fraction of the energy of a 78 MeV photon dissipated in the crystal was estimated to be about 90%. As the energy loss of relativistic electrons in thallous chloride is 9·7 MeV/cm, the total electron path length in the material corresponding to this energy dissipation is 7·2 cm. Assuming the electrons to be relativistic for the whole of this path, the number of photons radiated in the wavelength interval 3000 to 6000 Å would be 4400 if the refractive index of the crystal were constant in this range, and, with perfect light collection, 350 electrons would be liberated from the photocathode. This latter figure is based on a photocathode sensitivity of 40 μA/lm, and on the average spectral response of this type of tube, but as the sensitivity of the photomultiplier was determined with a standard tungsten lamp with a very different spectral distribution from that of Čerenkov radiation, the value of 350 electrons may be somewhat in error.

The ultra-violet absorption has two effects. Anomalous dispersion changes the number of photons emitted, and absorption reduces the number of these reaching the photocathode. As absorption is the dominant effect, the reduction was estimated by using the data given in the table for absorption of light by the crystal and assuming that the 4400 photons were emitted from a point at the centre of the crystal in directions making an angle θ with the crystal axis given by equation (2). On this basis, the number of photons reaching the cathode is reduced to 1860, and the number of photoelectrons to 130.

This number N of electrons, multiplied by the gain of the photomultiplier M produces across the anode capacitance C a voltage pulse of magnitude eMN/C. The total capacitance C was 18 pF, deduced from the observed decay time of the pulses, and the photomultiplier gain M, measured with continuous illumination at an anode voltage of 1320 V, was $1 \cdot 9 \times 10^6$. The pulse height predicted in this way for a 78 MeV photon is therefore 2·2 V with an anode voltage of 1320 V on the photomultiplier.

(*b*) *Resolution.* The relative variance V_Q of the pulse height distribution of a well-behaved counter of the scintillation or Čerenkov type with a homogeneous radiator may be shown to be

$$V_Q \doteq V_E + V_T + (1 + V_M)/N \qquad (3)$$

provided that V_E and V_T are small compared with unity, where V_E, V_T and V_M are the relative variances in the energy absorbed in the radiator, the mean transfer efficiency, and the multiplication factor of the photomultiplier respectively, and N is the average number of photoelectrons entering the dynode system in each pulse. The mean transfer efficiency is the probability that a scintillation or Čerenkov photon will liberate a photoelectron which enters the dynode system, averaged over all such photons produced by one primary event. This probability varies because of the different spatial distributions of the photons from different primary events.

In this case a contribution to V_E arises from the energy distribution of the photons selected by the monochromator. This distribution was calculated to be approximately rectangular, with a total width of about 10% of the mean value, and a relative variance, therefore, of 0·0008. A second and larger contribution is due to fluctuation in the amount of energy captured in the crystal. Assuming as above that an average of 10% of the energy of a 78 MeV photon is not captured, and that it escapes in the form of X-ray photons of greatest penetrating power, with energies therefore of approximately 3·5 MeV, the mean number of such photons escaping is 2·2. The relative variance due to random fluctuations in this number is 0·0056, giving a total value for V_E of 0·0064.

For a photomultiplier tube with stage gain m, V_M is equal to $1/(m - 1)$. Using for m in this formula the eleventh root of the value given in the previous section for the overall gain M, V_M is equal to 0·37, and with an estimated value for N of 130, the last term in equation (3) is equal to 0·0105.

It is difficult to make a satisfactory estimate of V_T, but the sum of the other two terms, 0·0169, may be taken as a lower limit to the value of V_Q. Assuming that the pulse-height distribution is approximately Gaussian, a lower limit of 31% is obtained for the resolution.

DISCUSSION AND CONCLUSIONS

The measured resolution (34%) of the counter for 78 MeV photons is not much greater than the lower limit estimated above. On the other hand the pulse height observed for 78 MeV photons with an anode voltage of 1320 V was 1·1 V, considerably smaller than the estimated value. In view of the agreement between the two values of the resolution, it does not seem likely that the number of photoelectrons liberated from the photocathode can be very much below the estimate of 130. The explanation of the smaller pulse height measured experimentally may be that the gain of the photomultiplier for large pulses is less than that measured with continuous illumination, although, in view of the apparent linearity with pulse height, this is not easy to understand.

It does not seem likely that a significant increase in the resolution of the counter can be made except by increasing the number of photoelectrons. Any reduction in V_E by using a larger crystal would probably be offset by the increased absorption due to longer light paths in the crystal. Some improvement could be made by using a more sensitive photomultiplier tube, but the biggest factor limiting the number of photoelectrons appears to be the ultra-violet absorption of the crystal. If this is characteristic of thallous chloride and not due to impurities, there seems little possibility of improving substantially the resolution of a Čerenkov counter using this material.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Foote, R. S., and Koch, H. W. *Rev. Sci. Instrum.*, **25**, p. 746 (1954).

(2) Kantz, A., and Hofstadter, R. *Nucleonics*, **12** (3), p. 36 (1954).

(3) Hofstadter, R. *CERN Symposium* 1956, Vol. 2, p. 75 (Geneva: CERN, 1956).

(4) Swartz, C. E. *Nucleonics*, **14** (4), p. 44 (1956).

(5) Jones, W. B., Kratz, H. R., and Rouvina, J. *Rev. Sci. Instrum.*, **28**, p. 167 (1957).

(6) Brabant, J. M., Moyer, B. J., and Wallace, R. *Rev. Sci. Instrum.*, **28**, p. 421 (1957).

(7) Schiff, L. I. *Quantum Mechanics*, 2nd. ed., p. 267 (New York: McGraw Hill Book Co. Inc., 1955).

(8) Weil, J. W., and McDaniel, B. D. *Phys. Rev.*, **92**, p. 391 (1955).

A d.c. and square wave a.c. resistance and voltage comparator

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A compact resistance and voltage comparator employing an isolating potential circuit with mechanical choppers has proved to be a versatile and accurate laboratory tool. Voltages can be compared with an accuracy of 10^{-8} V and resistors with an accuracy of 2 parts in 10^6 (d.c. operation) or 2 parts in 10^5 with automatic cancellation of thermal e.m.f. (square wave operation). When a d.c. amplifier and recorder are used, voltage and resistance differences may be recorded with an accuracy of about 2 parts in 10^3.

ice its original publication the isolating potential circuit comparing e.m.f.'s and resistances(1) has been put to ny uses. These uses have included the comparison of ndard thermocouples,(2) resistance thermometry(3) and re recently, in square wave operation, Hall coefficient and agneto resistance measurements.(4) Because of the diversity uses of the circuit we have found it desirable to have on d a general purpose unit which can be quickly and easily nsported from one part of the laboratory to another and verted to perform any of the above functions. Such a it must be able to operate either as a simple isolating tential comparator or as a square wave comparator for ncellation of large and variable thermal e.m.f.'s, the angeover being made quickly and without special wiring. should also be able to provide a range of currents through compared resistors and have provision for measuring th these currents and the unbalance voltage. This latter, resistance comparison measurements, varies linearly with difference in resistance. A general purpose comparator bodying these features has been built and, in conjunction h a Leeds and Northrup amplifier and recorder and a four minal resistance box, has proved to be a useful and satile laboratory tool.

BASIC COMPARATOR CIRCUITS

The basic circuits which the apparatus is designed to satisfy shown in Fig. 1.

Fig. 1(*a*) represents the d.c. resistance comparison circuit much as originally described. The two resistors R_v and T to be compared are connected in series with a source of current and their respective potential leads are connected as shown to the stationary contacts of two double-pole, double-throw, break-before-make choppers. High quality capacitors C_1 and C_2 are connected between the pairs of moving contacts so that the operation of the choppers connects each one alternately to one pair of potential leads and then the other. Since the choppers operate with a phase difference of 180° the capacitors are always on opposite sides. Any difference in the voltage drops across the two resistors is transferred through the chopper circuit by the capacitors and results in a net d.c. current in the potential leads which is indicated by the galvanometer. Equality of the voltages, i.e. equality of the resistors, gives a null reading which, since there is no potential lead current, is independent of lead resistances.

The current reversal to eliminate thermal e.m.f.'s shown here differs from the original one(1); the resistors are not reversed separately and the capacitors are reversed so as to retain the polarity of the voltage across them and minimize the effect of dielectric absorption.

Fig. 1(*b*) shows the basic circuit described by Dauphinee and Mooser.(4) Square wave a.c. is fed to the two resistors R_v and X, a resistive unbalance resulting in an a.c. signal in the potential leads, but a pulsing d.c. signal in any particular chopper lead. Any d.c. thermal e.m.f. that may arise

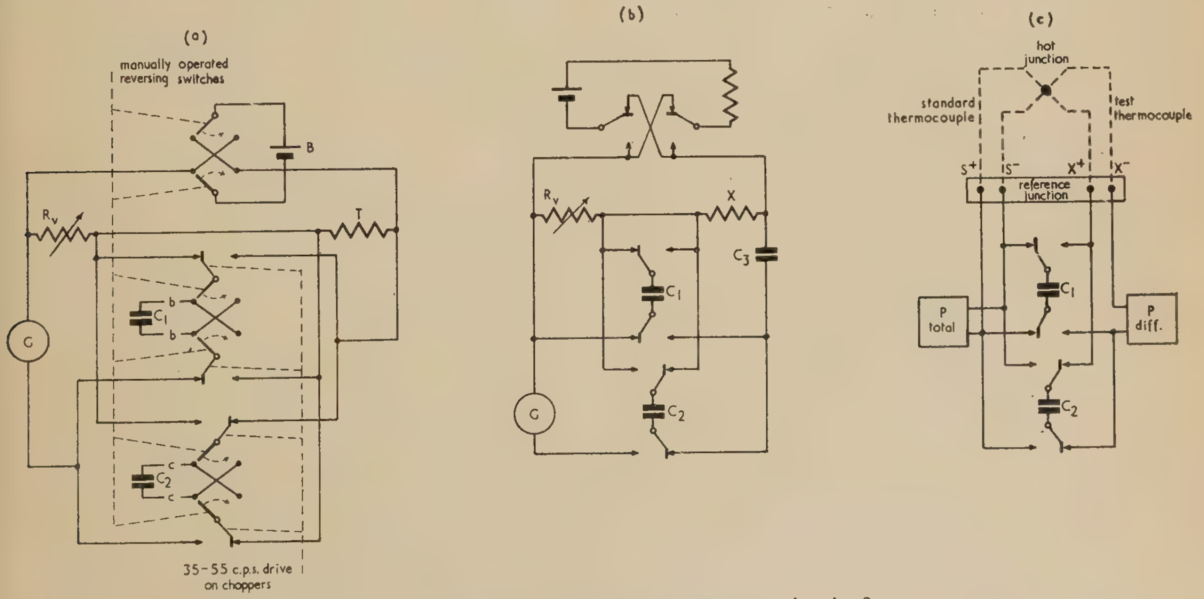

Fig. 1. Basic isolating potential comparator circuits for:

(*a*) d.c. resistance comparisons. (*b*) Square wave resistance comparisons. (*c*) Thermocouple comparisons.

in the resistors being compared or in their potential leads is blocked by a capacitor C_3 in one potential lead.

Fig. 1(*c*) represents the thermocouple comparison circuit. The thermocouples are electrically connected at the tips and a potentiometer (*P* diff.) is used to measure the difference in their e.m.f. while a second potentiometer (*P* total) measures the total e.m.f. of one of them.

In the circuit of Fig. 1(*a*) a null balance procedure is usually used, the balance point occurring when a reversal of current does not alter the reading of the detector. If, however, an unbalance voltage is being recorded it is more convenient to maintain the sense of the recorder deflexion on reversal and exhibit any thermal e.m.f. as a shift in the record, the true value being given by the mean of the two readings. This is best done by reversing the recorder with respect to the amplifier output, since thermal e.m.f.'s in the input circuit of the amplifier will then be included in the shift of the record.

The circuit of Fig. 1(*b*) is usually balanced to the null of the indicator or recorded without reversing provisions; reversals are only necessary if thermal e.m.f.'s are suspected in the chopper or detector circuit. The sensitivity of this circuit can be doubled by using a fourth chopper unit to switch the detector (galvanometer or d.c. amplifier) into whichever chopper lead happens to be carrying current at the time or by reversing it in a potential lead. An alternative form of detection of the unbalance signal consists of placing the detector transformer of an a.c. amplifier in series with the blocking capacitor; the amplifier output can then be demodulated in the usual manner with a chopper.

When recording the resistive unbalance (ΔR) with either the circuit in Fig. 1(*a*) or 1(*b*) the recorder deflexion is proportional to $I.\Delta R$, where I is the current. The current must therefore be known and should be intermittently exhibited as a deflexion on the recorder chart. This is easily accomplished by switching the recorder input to a fixed resistor of appropriate size which is also in the current circuit. When the current record is made to coincide with the chosen chart line the unbalance record will be compensated fo expansion of the chart provided that this is uniform acros the width of the chart and remains constant for the perio between current checks. Both of these conditions are usuall satisfied. A fixed pen marking on the chart the true zer position of the record pen allows a correction to be made fo the small lateral shifts of the chart lines that are likely t occur as a result of printing or tracking errors.

In the square wave circuit [Fig. 1(*b*)] the current checkin resistor must be located on the battery side of the reversin chopper. The shorted time of the chopper results in measured current that is higher than the effective current (i.e. the current flowing through the resistors while th capacitors are connected to them) by the fraction

$$\frac{\Delta I}{I} = \frac{\Delta t}{t} \times \frac{R_1}{R_2}$$

where Δt is the shorted time in a cycle of time t, R_1 is th resistance shorted out by the choppers and R_2 is the tota resistance when the choppers are not shorted. This fractio is small since $\Delta t/t$ is of the order of 0·03 and R_1/R_2 is normall around 0·01, a large value of R_2 being required to stabiliz the current against variations of converter contact resistance (50 V battery, 5 mA current, $R_1 = 100$ gives $R_1/R_2 = 0{\cdot}01$) The current error, therefore, can usually be held below 0·1 %

THE COMPOSITE UNIT

A circuit diagram of the composite unit is shown in Fig. 2 Current is supplied from a 45 V dry battery through a resist network that includes a 10 turn potentiometer for fine contr and a range switch that introduces the series resistors necessar for maximum currents of 10 mA, 2·5 mA and 50 μA. Th 0–10 milliammeter gives a rough value of the current whi the single decade potential divider (1 Ω steps) in the circui makes possible more precise current measurement (±0·15% by applying the voltage drop across the appropriate resistanc

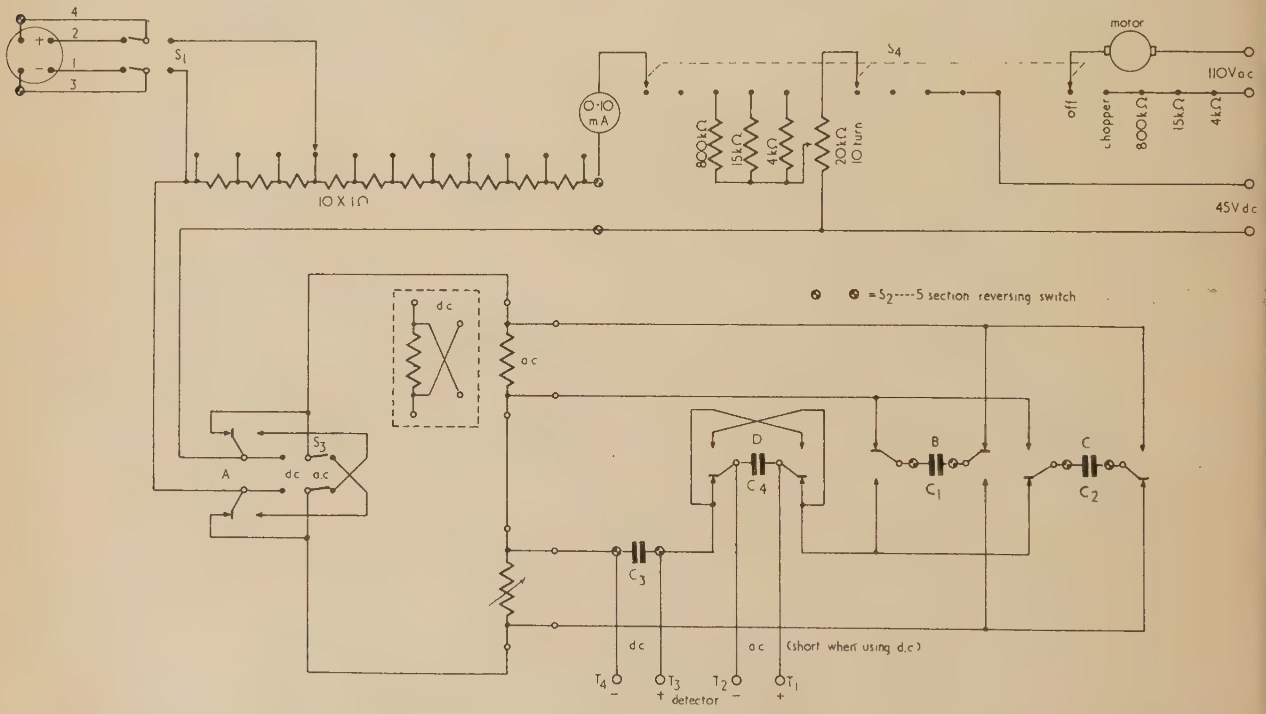

Fig. 2. Circuit diagram of the composite unit

a 10 mV recorder *via* the current check switch S_1. Switch allows reversal of the current for elimination of thermal .f.'s, of the charged capacitors so as to maintain the larity of the voltage across them and of the input to the order so as to retain the sense of its deflexion. The pper unit *A* can be put in series with the current supply d is used to convert the d.c. current, by reversal, to square ve a.c. Switch S_3 makes the selection between d.c. and are wave operation.

The isolating potential unit is of the usual two capacitor e, but has an additional chopper unit (*D*) which reverses detector terminals T_1 and T_2 (used for square wave asurements) in one of the potential leads. Fig. 3 shows phasing of the four chopper units *A*, *B*, *C*, *D*. A filter acitor C_4 is connected across T_1 and T_2, but for d.c. opera- n these terminals are shorted together. Capacitor C_3 s as the blocking capacitor in square wave operation and the filter capacitor across the detector terminals T_3 and T_4 d in d.c. operation.

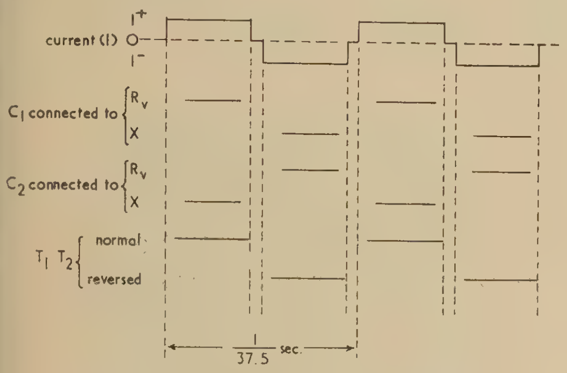

Fig. 3. Phasing of the chopper units

The current control switch S_4 is wired so that as it is turned ckwise from off the chopper motor starts but no battery rent flows, then progressively larger currents of 50 μA, 5 mA and 10 mA (maximum) appear, each range being ustable from zero to maximum by the helipot.

The five circuit reversal switch S_2 is a special wafer switch de up from a kit. The current reversal is make before ak to prevent sparking and the capacitors are disconnected ore the current reversal begins and reconnected in the erse direction after the current reversal is completed. lar condensers (by Film Capacitors Inc., New York) are d throughout with plug connexions as shown at *bb*, *cc* in . 1(*a*) to facilitate change of capacity or change of type, . to polystyrene in the few cases where this is desirable. e capacities C_1, C_2, C_4 and $\frac{1}{2}C_3$ are equal and are matched a circuit resistance of 125 Ω for the 38 c/s chopping quency used.* However, the circuit resistances can vary siderably from this value before the sensitivity or the ancing time is appreciably affected.

Two sets of current and potential terminals are provided; se for the reference resistor are in a line with the potential minals slightly offset, those for the unknown resistor are a diamond. The potential terminals of the latter are inter- nged when there is a changeover between d.c. and square ve operation. For less accurate work a four-pin plug in allel with the reference resistor terminals allows various resistors or resistance boxes to be connected rapidly and easily. A four-pin amphenol socket receives the output from the d.c. amplifier and provides the input to the recorder.

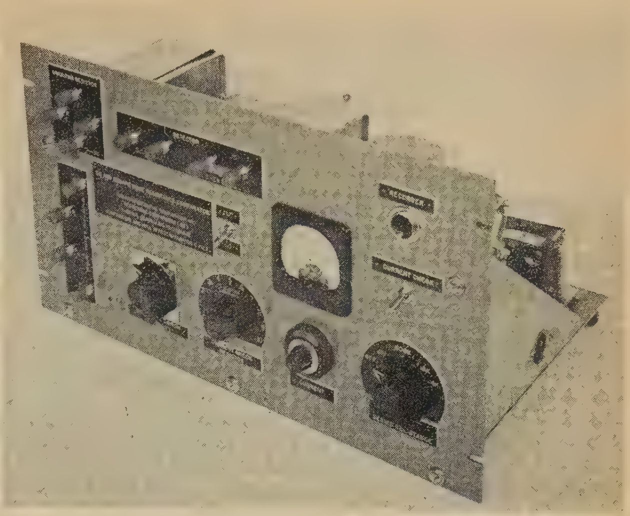

Fig. 4. Picture of the completed equipment

A picture of the completed unit is shown in Fig. 4. This unit is intended for rack mounting with a suitable linear amplifier and recorder (e.g. microvolt amplifier and 10 mV Speedomax by Integra, Leeds and Northrup Ltd.) The mechanical choppers are of National Research Council design and were supplied by H. Tinsley Ltd. These and the 300 μF of low voltage Mylar condensers represent the major part of the cost of the comparator. It is possible to achieve a certain amount of simplification in design and construction by using an instrument that operates on d.c. only. In this case the chopper filter system can be modified to improve the rejection of stray a.c. voltages.$^{(5)}$

CONCLUSION

Both the double purpose and the simplified comparators mentioned in the preceding paragraph have found a number of applications in this laboratory. Their freedom from lead resistance errors makes them particularly useful for resistance thermometry in low temperature, temporary or remote arrangements. In these applications the thermometer can be several hundred feet from the comparator, four conductor miniature cables being sufficient for the connections between them. In square wave operation resistances are read off directly without reversals even when d.c. e.m.f.'s of the order of volts are in the potential leads. Balances may be taken to 10^{-8} V with an accuracy of resistance comparison for circuits less than 100 Ω of about two parts in 10^6 for d.c. and two parts in 10^5 for square wave operation. On those rare occasions when higher accuracy is required an improvement by a factor of five or ten can be obtained by measuring the effect of capacity to ground in the chopper-capacitor circuit$^{(1)}$ and making the necessary correction.

REFERENCES

(1) Dauphinee, T. M. *Can. J. Phys.*, **31**, p. 577 (1953).
(2) Dauphinee, T. M. *Can. J. Phys.*, **33**, p. 275 (1956).
(3) Dauphinee, T. M., MacDonald, D. K. C., and Preston-Thomas, H. *Proc. Roy. Soc. A*, **221**, p. 267 (1954).
(4) Dauphinee, T. M., and Mooser, E. *Rev. Sci. Instrum.*, **26**, p. 660 (1955).
(5) Dauphinee, T. M. *Rev. Sci. Instrum.*, **28**, p. 767 (1957).

Condenser size is computed from equation $2RfC = \alpha$, where = current resistance, f = chopping frequency, C = capacity, α = proportion of the cycle during which the chopper contacts closed.$^{(1)}$ The chopping frequency used minimizes interence from the 60 c/s line frequency.

A gas target and nuclear plate camera

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[*Paper first received* 16 *July, and in final form* 14 *August*, 1957]

A windowless gas target capable of maintaining a pressure of up to 2 mm of mercury has been constructed to determine the differential cross-section of charged particle reactions. Targets of this type have been used to examine (*d*, *p*) and (*d*, α) reactions in the range 15 keV to 1 MeV.

INTRODUCTION

When investigating nuclear reactions in which the yield and angular distribution of the reaction products are sharply dependent on the energy of the bombarding particles, it is necessary to use a "thin" target. While, by evaporation techniques, it is possible to produce a "thin" target, such targets require some form of backing; this will scatter reaction products moving in the forward direction. In the case of reactions whose cross-sections are of the order of fractions of a millibarn, beam currents of the order of tens of micro-amps must be used; the backing must then be thick enough to dissipate the power developed in the target. In addition, it is difficult in any system evacuated by oil-pumps to prevent the formation of a layer of carbon on the surface of the target.

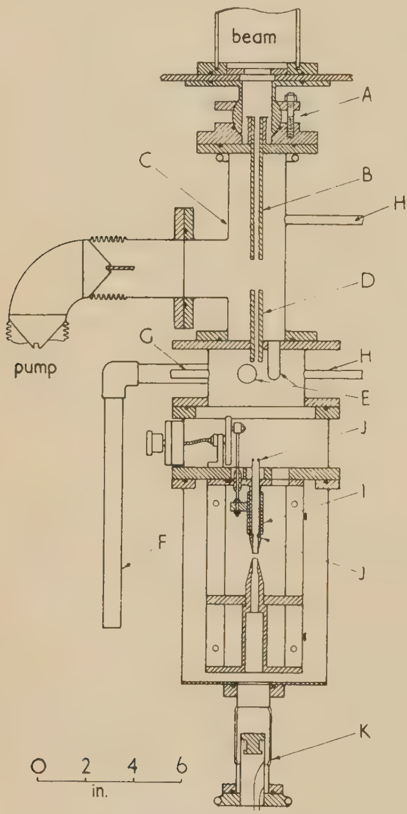

Fig. 1. Diagram of apparatus

A, cup-and-ball joint; *B*, upper canal; *C*, intermediate chamber; *D*, lower canal; *E*, external bye-pass; *F*, liquid air trap; *G*, gas supply; *H*, gauges; *I*, tubular shutter; *J*, stops; *K*, calorimeter.

Under these conditions, the most satisfactory target is on in which the target material is a gas at low pressure. I addition to the factors already mentioned, the optimum pressure depends on the desired exposure time. If pressure of a few millimetres of mercury can be maintained, the othe parameters can be varied fairly widely to suit experimenta conditions. As the beam of bombarding particles normall comes from an accelerating system at high vacuum, it necessary to isolate the target gas either by a window or by differential pumping system. The former has the disadvantag of producing an uncertain decrement in beam energy.

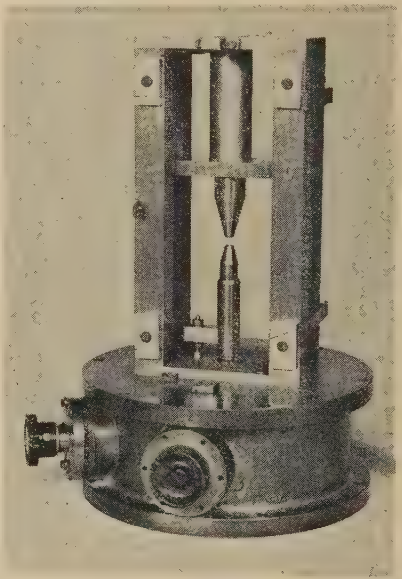

Fig. 2. Camera. Beam enters from below

A windowless gas target, shown in Fig. 1, using a differentia pumping system has been developed in which pressures c up to a few millimetres of mercury can be maintained. I has been designed for use with nuclear emulsions as detector of the reaction products; in order that absolute cross-section may be measured, a calorimeter has been incorporated t measure the beam-intensity. The design of the target, an the use of these components under the conditions existin in a gas-filled camera (Fig. 2), are discussed below.

DIFFERENTIAL PUMPING SYSTEM

The target is separated from the main accelerator by tw canals whose axes are alined optically. The upper canal i 15 cm long and 4 mm in diameter, the lower 7·5 cm long an 3 mm in diameter, and they are separated in the intermediat chamber by a gap of about 3 cm. This chamber is con tinuously evacuated by a 4 in. oil diffusion pump. Whe re is a pressure of 1·5 mm of mercury of nitrogen in the get, a pressure of 10 μ of mercury can be maintained in intermediate chamber; this gives a loss from the target 20 c.c./min of nitrogen at S.T.P., and a leak into the main celerator of 0·04 c.c./min of nitrogen at S.T.P.

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* Now at English Electric Co. Ltd., Whetstone, Leicester.
† Now at Clarke Chapman Co. Ltd., Gateshead on Tyne.

The target gas is normally stored in a reservoir and admitted the target continuously through a needle-valve. An ernal ½ in. bye-pass, closed when running, is provided to mp down the target chamber after loading with fresh plates, d to this is connected a liquid air trap to condense the ter-vapour released by the emulsions. Pirani gauges are ed to monitor the pressures in the intermediate and target ambers; the pressure of the target gas is measured by a ibrated McLeod gauge.

When common gases were in use in the target, the inter-diate pump discharged to the atmosphere. When a rare eous isotope was in use, the oil diffusion pump was laced by a mercury pump, fitted at input and output with ps which were maintained at −28° C. The diffusion pump s backed by the target itself, the gas thus being circulated ough the target. The change to mercury was necessary cause of the high back-pressure, and also because, in a culating system, the decomposition products of the oil oduce a steadily increasing source of impurity in the target . Under these conditions, the only loss of target gas is e to the small leakage into the main accelerator.

To aline the target so that its axis coincides with the beam, assembly is attached to the lower end of a cup-and-ball cuum joint(1); the top end of the upper canal is protected a stainless steel disk and the canal positioned so that the ntre of the disk is at the centre of rotation of the joint. e disk can be observed through two 90° glass prisms let o the section above, and the position of the beam adjusted til it enters the canal centrally. The entire target is then tated about the joint until the maximum beam current is tained at the far end of the target. This involves flexible nnexions to the intermediate pump, to the gas supply d to the gauges; the weight of the assembly is taken by a ble and spring.

THE CAMERA

The design of the camera using glass-backed nuclear ulsions is based on that of Moffatt, Roaf and Sanders.(2) e beam after leaving the lower canal passes through the s-filled target, providing a long cylindrical source of action products. In order to prevent charged particles om reaching the detectors except from a small reaction lume, the beam is enclosed throughout its length in two ass cylinders of 5 mm minimum inside diameter and 1 mm ll thickness, except for a gap 5 mm long. The ends of ese screening cylinders are tapered to a cone of 15° half-gle; the cones are tipped with copper-nickel alloy, and eir edges trimmed off to give a minimum thickness of 1 mm. This shape reduces to a minimum the number of rticles which have lost energy after penetrating the tips the cones. Thus it is possible on a single pair of plates to tect particles which leave the reaction volume in directions aking angles of from 15° to 155° with the positive direction the beam.

The duration of the exposure is controlled by a tubular utter which can be slid over the gap by means of a crank d slotted cross-head. The shutter can be opened or closed less than a second. To avoid any chance of the beam riking the edges of the cones, additional stops of 3 mm ameter are placed above and inside the upper screening linder.

In its passage to the reaction volume from the accelerator through the gas target, the beam loses energy by ionization. This loss can however be estimated,(3) and is only 10–30 keV; the "thickness" of the reaction volume itself is at most a few hundred electron-volts.

Two nuclear plates, 19 cm × 10 cm are placed symmetrically on either side of the reaction volume, with their major axes parallel to the beam direction. They are separated by four steel rods ground to a length of 7 cm, their lateral position being defined by three stops bearing against the edges of the glass backing, Because of the drying out of the emulsion in the vacuum of the target, there is a tendency for the plates to bow outwards; they are therefore backed by aluminium plates secured firmly to the frame of the camera. To determine the position of any chosen area on the plates relative to the reaction volume, a template is used in which was cut a series of fine slits. From this a co-ordinate system can be transferred to the emulsion by means of a fine scriber. Positions on the plate relative to the target volume can be determined to better than 0·1 mm.

To calculate the yield of the reaction in any direction from the number of tracks in any given area of the plates, it is necessary to allow for the finite area counted, for the finite size of the reaction volume, and for the fact that the position of the reaction volume seen from any direction depends on that direction. This last factor is easily assessed, but the first two factors introduce a fivefold integral. This integral has been evaluated by expansion in power series.

ABSORBER FOILS

In most applications of the camera, the nuclear plates will have to be covered with metal foils. These are necessary to screen the emulsion from fogging by the light generated by the beam in its passage through the target gas, and also from primary particles scattered from the beam.

The second use of foils is to reduce the range of the most energetic of these products so that their tracks shall always terminate in the emulsion. As the tracks of all particles leaving the reaction volume at a given angle to the beam are distributed along a hyperbola, it is possible by using different foil thicknesses over different portions of the hyperbola, to distinguish between more than one group of particles in a single exposure. The absorbers must be supported by spacers so as to be clear of the plates as aluminium foils adhere easily to the emulsion surface and cause chemical fogging.

THE CALORIMETER

Measurements of the track-density in different areas of a single pair of plates give directly the relative differential cross-sections for the reaction at the various angles and there is no need to know the density of the gas, the exposure time, nor the intensity of the beam. A knowledge of these is required if the absolute value of the cross-sections are to be obtained. The beam after passing through the reaction volume strikes the head of the calorimeter placed at the end of the lower screening cylinder. The principles of this method of measuring beam intensities have been described by Sanders.(4) In the present target, with which it was intended to use beam currents of from 2 to 50 μA, from ½ to 1 MeV energy, and exposures of the order of 1 hour, a calorimeter was designed which could measure power inputs of from 1 to 50 W, with an accuracy of 50 mW, and had a short thermal time-period.

In calculating the beam intensity, it is also necessary to know the beam energy. It must be remembered that the energy of the beam striking the calorimeter is lower than when it passes through the reaction volume; this diminution in energy may be calculated from published data.$^{(3)}$

CONCLUSION

By the use of a target of this type, nuclear emulsion techniques have been applied in the range of bombarding energies 15 keV to 1·1 MeV. By varying the pressure of the target gas, the beam intensity and the exposure time, it is possible to determine angular distributions and values of the differential cross-sections from 10^{-3} mb/steradian up to the largest values known.

In a series of measurements made with this target the *absolute* values of differential cross-sections were obtained with a probable error of 6%. The accuracy of a measured angular distribution and the *relative* differential cross-sections for different particle groups at any one energy, depend principally on the number of tracks counted, as the geometrical errors are less than 1%.

ACKNOWLEDGEMENTS

Two of us (D. L. B. and R. S. H.) would like to thank the D.S.I.R. for maintenance grants, one of us (G. L. S.) would like to thank the Rhodes Trustees for a scholarship.

REFERENCES

(1) Lee and Young. *J. Sci. Instrum.*, **31**, p. 70 (1954).
(2) Moffatt, Roaf and Sanders. *Proc. Roy. Soc. A*, **212**, p. 220 (1952).
(3) Reynolds, Dunbar, Wenzel and Whaling. *Phys. Rev.*, **92**, p. 742 (1953).
(4) Sanders. *J. Sci. Instrum.*, **26**, 36, 1949.

Automatic temperature programming and recording for a platinum-rhodium furnace

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[*Paper first received* 3 *June, and in final form* 25 *July*, 1957]

The resistance of the platinum–rhodium alloy varies with temperature so much that a fully automatic programming controller must incorporate a device for adjusting the voltage applied to the winding as the furnace temperature changes. The way in which this was achieved, by means of a servomechanism, is described.

None of the commercially available programming temperature controllers is immediately suitable for use with a platinum or platinum rhodium alloy wound furnace since the resistance of the winding increases considerably as the temperature rises. Thus the voltage applied to the winding must be adjusted continuously as the temperature changes and this must be done automatically if the furnace is to be left unattended. This has been achieved here by the use of a simple servomechanism.

The temperature control instrument was a proportional on-off programming unit (by Kelvin and Hughes, Ltd.) which operated from a thermocouple in the furnace. The temperature cycle was recorded on a strip chart self balancing potentiometer (by Honeywell-Brown Ltd.) from a second thermocouple.

The voltage required to give a constant current in the winding at any given temperature was calculated from the temperature coefficient of resistance of the platinum 10% rhodium alloy used. This curve together with the curve of temperature versus millivolts for the thermocouple (13% Rh–Pt/Pt) was used to give the relationship between the millivolts obtained from the thermocouple and the voltage required across the furnace winding. It is seen (Fig. 1) that this curve is almost linear. Thus by linking the recorder pointer with a Variac transformer controlling the input voltage to the furnace, adequate control of this voltage is obtained. Direct mechanical linkage is impossible even though the pointer is power driven so a servo loop in conjunction with a motorized Variac transformer was used (Fig. 2).

In the recording potentiometer the printing bar B is attached to a wire W which is looped around a groove on a large gear wheel G_1 which is geared to the brush on the potentiometer slide wire. Thus the wheel G_1 and the printing bar both follow the balance point, the linear displacement of the printing bar across the chart being obtained from the angular movement of G_1 which turns through nearly 360° for a full-scale traverse of the printing bar (0–1650° C).

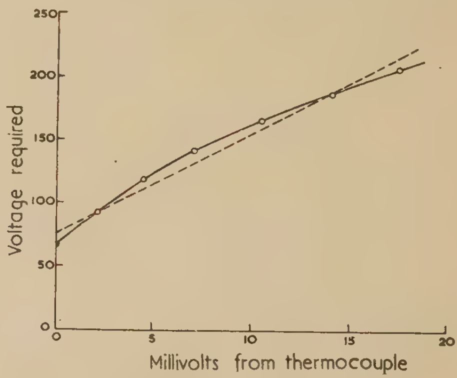

Fig. 1. Graph of millivolts obtained from thermocouple against voltage required across furnace winding

○, ideal variation; – – –, adequate linear approximation.

A small pinion P_1 on the spindle of a 2 in. 50 V 50 c/s Magslip transmitter M_1 (A.P. 6550) was meshed, through an intermediate gear into the wheel G_1 of the recorder. This nsmitter was connected to a 2 in. 50 V 50 c/s coincidence nsmitter M_2 (A.P. 10682) whose small pinion P_2 was

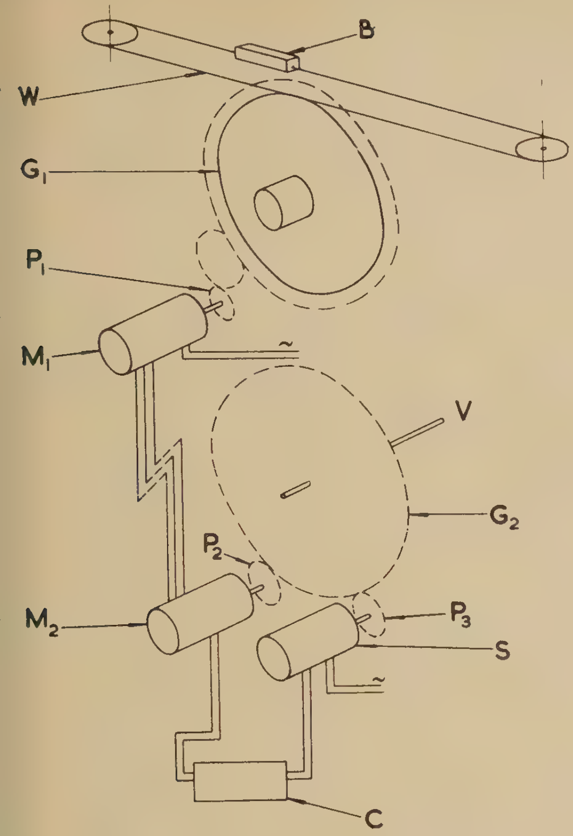

Fig. 2. Diagram of apparatus used

, printing bar; C, amplifier; G_1, gear on recorder; G_2, gear n Variac transformer shaft; M_1, Magslip transmitter; M_2, Iagslip coincidence transmitter; P_1, P_2, P_3, pinions; S, servo motor; V, Variac transformer shaft; W, wire.

shed into a large gear wheel G_2 on the shaft of the Variac nsformer. When the two transmitters are out of phase an error signal results and is fed into an amplifier C (by Honeywell-Brown Ltd. type No. 351921–1 without converter). The output of this amplifier feeds a servo motor S (by Honeywell-Brown Ltd., type No. 76750–3) which turns G_2 and hence P_2 in such a direction as to reduce the error signal. An induction generator to prevent hunting was not found to be necessary.

Details of the gear to be used on the Variac transformer shaft are easily calculated from the average slope of the graph in Fig. 1. If x mV causes an angular rotation of θ degrees in G_1 and an output voltage change of y V from the Variac transformer requires the shaft to turn through ϕ degrees then the slope y/x of the graph can be evaluated in terms of ϕ/θ. Also as can be seen from Fig. 2,

$$\phi/\theta = g_1p_2/p_1g_2$$

where g_1, g_2, p_1, and p_2 are the numbers of teeth on G_1, G_2, P_1 and P_2 respectively. Hence

$$g_2 = g_1p_2\theta/p_1\phi$$

The pinions P_1 and P_2 are not critical and for convenience $p_1 = p_2$ thus

$$g_2 = g_1\theta/\phi$$

Since the pinion P_1 rotates many times for a 360° rotation of G_1 the coincidence position is not unique. Care is therefore necessary when switching on the furnace after shut down to check that the original coincidence setting has not been altered. It is convenient to be able to alter the Variac transformer setting independently of the servo loop. This is achieved by replacing the coincidence transmitter output by a voltage obtained from the heater winding of the amplifier transformer. The phase of this voltage can be changed by 180° to drive the servo motor up or down.

Safety precautions include a fusible link, a circuit-breaker (by G.E.C. Ltd.) and a broken thermocouple device actually in the controller. This servo-mechanism should be capable of being adapted to operate from any self balancing potentiometer and has in fact been fitted to a circular chart programming and recording proportional controller potentiometer (by Honeywell-Brown Ltd.) in this laboratory.

The authors wish to thank the Admiralty for permission to publish this work.

An apparatus for the determination of dynamic elastic moduli at low strains

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An electronic apparatus is described for the determination by a resonance method of Young's modulus and the modulus of rigidity of materials in the form of cylindrical rods. Results can be obtained at strains as low as 10^{-9}. The method of calculation of the moduli from the observed resonant frequencies is given.

Several articles which have recently been published indicate the growing interest in the elastic moduli of single crystals. An admirable general review has been given by Hearmon,(1,2) and also by Nowick,(3) although Nowick specifically refers to internal friction. It has been shown that there is a need for an apparatus for the measurement of the moduli with the specimen subjected to only low strain, but which nevertheless will yield accurate results. A suitable method is where the specimen, in the form of a cylindrical rod, is set into resonant vibration by the electrostatic forces produced when an alternating voltage is applied between the specimen and a suitably placed electrode. This method has been used by Bancroft and Jacobs,(4) Bordoni(5) and Pursey and Pyatt.(6) In the apparatus used by Bordoni and by Pursey and Pyatt, the specimen and electrode form part of a tuned circuit of a very high frequency oscillator (about 60 Mc/s), so that the vibration of the specimen produces a frequency-modulated signal. In Pursey and Pyatt's apparatus this signal is amplified and discriminated by a quarter-wavelength tuned line operating at a frequency just off that of the unmodulated oscillator. This method of discrimination, however, detects also any amplitude modulation which may be present arising from stray coupling and from "noise" voltages.

The apparatus described in this paper, while making use the above method of exciting the vibrations in the specime and producing a frequency-modulated signal, employs nonode valve as the discriminator, which greatly attenuat the unwanted voltages in the frequency modulated signa Resonant vibrations of the specimen can be observed up t frequencies of about 150 kc/s, but this range can, if require be extended considerably by increasing the bandwidth of th amplifier which is between the frequency-modulated oscillat and the nonode. For a cylindrical specimen of length abo 15 cm and of cross-sectional area about $0{\cdot}3$ cm^2, one end which can be made plane to about $0{\cdot}02$ mm, an amplitud of vibration of about 1 Å can be detected. The maximu strain in the specimen is then of the order of 10^{-9}. Greate amplitude sensitivity can be achieved but only at the expens of the frequency range covered by the apparatus.

THE ELECTRONIC APPARATUS

The very high frequency (70 Mc/s) oscillator consists o triode-connected pentode with a quarter-wavelength line the grid, and the specimen electrode is connected to the gri by a half-wave line. To obtain the high amplificatio

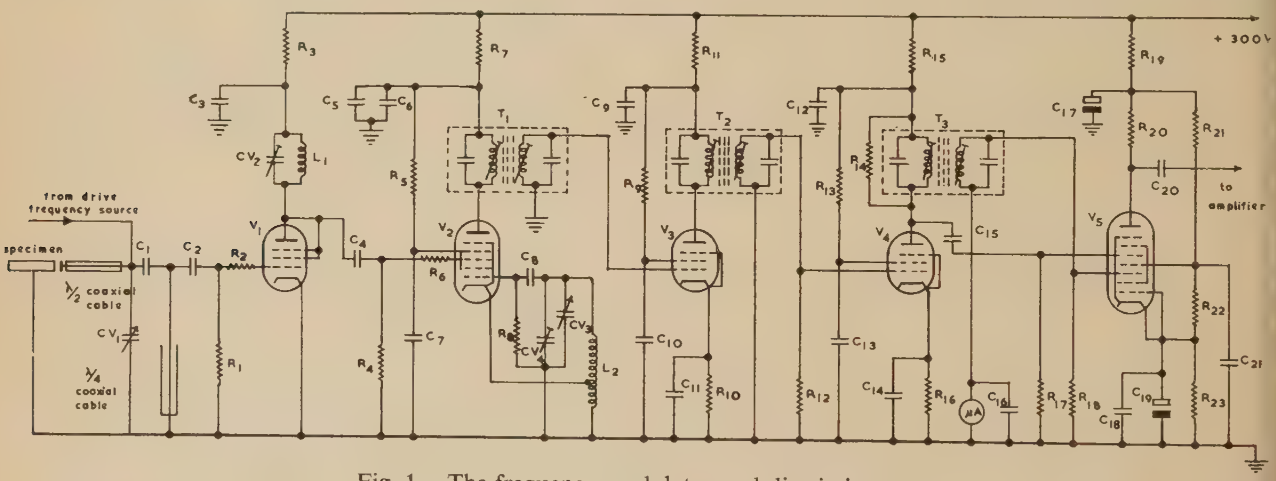

Fig. 1. The frequency modulator and discriminator

$R_1 = 10$ kΩ
$R_2 = 39$ Ω
$R_3 = 10$ kΩ
$R_4 = 1$ MΩ
$R_5 = 33$ kΩ
$R_6 = 1$ kΩ
$R_7 = 4{\cdot}7$ kΩ
$R_8 = 22$ kΩ
$R_9 = 60$ kΩ
$R_{10} = 160$ Ω
$R_{11} = 4{\cdot}7$ kΩ
$R_{12} = 22$ kΩ*
$R_{13} = 60$ kΩ
$R_{14} = 47$ kΩ*

$R_{15} = 4{\cdot}7$ kΩ
$R_{16} = 160$ Ω
$R_{17} = 100$ kΩ
$R_{18} = 22$ kΩ*
$R_{19} = 2$ kΩ
$R_{20} = 50$ kΩ
$R_{21} = 34$ kΩ (2 W)
$R_{22} = 3{\cdot}9$ kΩ
$R_{23} = 560$ Ω

$C_1 = 50$ pF
$C_2 = 22$ pF
$C_3 = 1000$ pF
$C_4 = 0{\cdot}5$ pF

$C_5 = 1000$ pF
$C_6 = 0{\cdot}1$ μF
$C_7 = 1000$ pF
$C_8 = 50$ pF
C_9–$C_{14} = 0{\cdot}01$ μF
$C_{15} = 1000$ pF
$C_{16} = 0{\cdot}01$ μF
$C_{17} = 4$ μF
$C_{18} = 0{\cdot}01$ μF
$C_{19} = 25$ μF
$C_{20} = 0{\cdot}01$ μF
$C_{21} = 1$ μF

Cv_1–$Cv_3 = 15$ pF
$Cv_4 = 30$ pF

$L_1 = 1{\cdot}2$ μH
$L_2 = 0{\cdot}2$ μH

V_1 = EF91
V_2 = 6BE6
V_3, V_4 = EF85
V_5 = EQ80

T_1–T_3 = I.F. transformer (12 Mc/s)

μA = 250 μA f.s.d.

* The value of these resistors may need to be modified to suit the particular transformer used.

essary before frequency discrimination, the frequency of Mc/s is changed to about 12 Mc/s by a heptode frequency nger, and then the signal is passed through a two-stage plifier of about 150 kc/s bandwidth. The frequency disnination is achieved by a nonode, a phase-sensitive valve ich is almost insensitive to amplitude modulation above a tain input voltage.

he detailed circuit diagram of the frequency-modulated illator, the amplifier, and the discriminator is shown in . 1.

THE DETERMINATION OF DYNAMIC ELASTIC MODULI

a) *Longitudinal vibration* (*Young's modulus*). The specin, in the form of a cylindrical rod of circular cross-section, ıeld at its centre by three knife edges, two of which form V" while the third, which is spring loaded, gently holds specimen into the "V." Deformation and strain in the cimen are therefore negligible. As all the clamping is oss the central section, additional supports along the gth of the rod are not required, except when very soft cimens are used. There is thus little mechanical damping the vibration.

he method of exciting longitudinal vibrations in the cimen is similar to that used by Pursey and Pyatt.(6) e electrode, a metal disk about $\frac{1}{4}$ in. diameter, is brought close as possible to one end of the specimen without ually touching it, by adjusting the gap precisely by a fine hed screw.

oung's modulus (E) for the specimen is calculated from asurements of the fundamental and harmonic resonant quencies of the longitudinal vibrations in the following way. The relation for the pulsatance p in a rod of length l, lius a, Poisson's ratio σ, and density ρ, is given by hhammer(7) as

$$p = \gamma(E/\rho)^{\frac{1}{2}}(1 - \tfrac{1}{4}\sigma^2\gamma^2a^2) \qquad (1)$$

resonance $\gamma = n\pi/l$, where n is the harmonic number. e frequency f_n of resonance of the nth harmonic is, theree,

$$f_n = \frac{n}{2l}\left(\frac{E}{\rho}\right)^{\frac{1}{2}}\left(1 - \frac{\pi^2}{4l^2}\,\sigma^2n^2a^2\right) \qquad (2)$$

$$\frac{f_n}{n} = \frac{1}{2l}\left(\frac{E}{\rho}\right)^{\frac{1}{2}}(1 - kn^2) \qquad (3)$$

ere k is a numerical constant.

Hence, a graph of f_n/n against n^2 should be linear. The ercept on the f_n/n axis is equal to $1/2l\,(E/\rho)^{\frac{1}{2}}$, from which ung's modulus can be obtained.

b) *Torsional vibration* (*rigidity modulus*). Torsional vibrans are excited in the specimen by a method similar to that scribed by Bancroft and Jacobs.(4) A small steel vane about × 10 mm and about 0·1 mm thick has a circular disk of out 6 mm diameter soldered at the centre of a long side of vane and at right angles to the plane of the vane. The k is attached to one end of the specimen by an adhesive such a way that there is good electrical contact between the k and the specimen. The specimen is supported between the knife edges, as for the longitudinal vibrations. A drive electrode as shown in Fig. 2 is used, and this electrode can be rotated to adjust the gap between it and the vane.

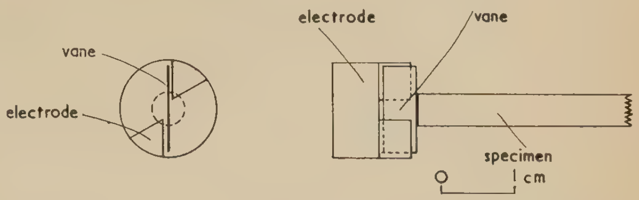

Fig. 2. The drive electrode assembly for torsional vibrations

The vane affects the resonant frequency of the specimen in two ways. Because of the inertia of the vane the rod is loaded. The loading of a cylindrical rod of circular cross-section by an inertial member has been discussed by Morris,(8) but he derives an expression for the torsional frequency only for $I_v \gg I_r$, where I_v and I_r are the moments of inertia of the vane and rod respectively, about the rod axis. In the present investigation, however, $I_v \ll I_r$. It can be shown by an extension of Morris's work that in this case the torsional resonant frequency is given by $(1/2l)(1 - I_v/I_r)(\mu/\rho)^{\frac{1}{2}}$ where μ is the rigidity modulus of the rod. The term I_v/I_r is, in most practical cases, small enough to be neglected.

However, it has been found experimentally that it is important to have the specimen of such a length that its torsional resonant frequency differs considerably from any of the resonant frequencies of the vane. If this is not the case, coupling between the two vibrational systems may occur. The resulting frequency shift depends on the excited mode of vibration of the vane, and the "Q"s of the specimen and vane. With a steel rod and a steel vane, a frequency shift of as large as $1\frac{1}{2}\%$ has been found.

ACKNOWLEDGEMENTS

The author thanks Prof. A. M. Taylor and Mr. S. Weintroub of the Physics Department of the University of Southampton for helpful discussions, and also members of the Electronics Department for technical assistance.

REFERENCES

(1) Hearmon, R. F. S. *Rev. Mod. Phys.*, **18**, p. 409 (1946).

(2) Hearmon, R. F. S. *Advances in Phys.*, **5**, p. 323 (1956).

(3) Nowick, A. S. *Progress in Metal Physics*, Vol. 4, p. 1 (London: Pergamon Press, 1953).

(4) Bancroft, D., and Jacobs, R. B. *Rev. Sci. Instrum.*, **9**, p. 279 (1938).

(5) Bordoni, P. G. *Nuovo Cimento*, **4**, p. 177 (1947).

(6) Pursey, H., and Pyatt, E. C. *J. Sci. Instrum.*, **31**, p. 248 (1954).

(7) Pochhammer, L. *Crelles. J. Math.*, **81**, p. 324 (1876).

(8) Morris, J. *The Strength of Shafts in Vibration*, p. 153 (London: Crosby Lockwood, 1929).

A note on progressive codes for positive and negative indication

By W. T. Bane, B.Sc., A.M.I.E.E., National Physical Laboratory, Teddington, Middlesex

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The note describes a simple modification to progressive codes used in coded-plate digitizers so that a signed readout can be obtained. Little increase in the complexity of the decoding equipment is necessary and neither the accuracy of readout nor the maximum tolerance of the digitizer to mechanical imperfections is impaired.

The use of progressively coded plates for measuring digitally the position of mechanical members is now fairly common practice.(1, 2)

They are in theory capable of giving an accuracy of ±½ a division; this situation is unaltered for plates that are required to give negative indications of position if they are marked below the zero with the coding for the complement of the displacement. Thus, about the zero, a "decimally" coded plate might read 03, 02, 01, 00, 99, 98, etc., and, furthermore, by virtue of the way in which reflected coded-decimal codes are usually constructed (see Refs. 1 and 2), the progressive property will be maintained. For such a plate, the coding for all readings below zero will exceed 49 and these readings can be tabulated as negative numbers by taking their complement on 100. This, however, will require a relatively large increase in the readout equipment; a similar situation will apply for other progressive codes such as reflected binary (Gray code).

Where a signed readout is required, the added complication of equipment can be avoided by modifying the coding on the plate, but this is not merely a matter of adding a sign element to a suitable progressive numerical coding as this will involve a change in two code elements at one point (e.g. +02, +01, +00, −01, −02, the double change taking place between +00 and −01). A solution that has been used, is to introduce a double coding and put the sign change between the two codings (i.e. +02, +01, +00, −00, −01, −02), but this will introduce an error into the readout; positive numbers will be displaced by $+\frac{1}{2}$ a division and negative ones by $-\frac{1}{2}$ giving a total error in readout of ±1 division. External circuitry could be used to restore the original accuracy, but as this will involve an addition operation, no simplification would result. Indeed, such a method is only a circuitous way of performing the complementing process mentioned above.

An alternative approach makes use of a "double zero" in which both zero divisions are on the plate reduced to half the size of the others. However, as the size of the code divisions represents the maximum tolerance of the device to mechanical imperfections the result of this course is to reduce this tolerance to half, which may not be practicable.

We describe below a method of modifiying a progressive numerical code for signed readout which is free from the accuracy and tolerance disadvantages that have been pointed out and for which the decoding process is not very much more complicated than that for the unsigned code. Consider a plate marked in a progressive code to which a sign element has been added so that it reads +02, +01, +00, −01, −02. As has been pointed out, there will be a change in one of the numerical code elements and in the sign element between +00 and −01. If in the coding, the numerical element that changes is now inverted (i.e. 0 becomes 1 and vice-versa) for negative numbers, its change between +00 and −01 will have been eliminated so that only the sign element will change at this point. As the coding for negative numbers will still be progressive the whole coding is now progressive. Decoding is simple; when a negative sign is read, the specified element is inverted before proceeding normally.

In certain circumstances, however, the situation can become a little more involved, as in a circular plate where there are sign changes both at 0° and at 180°, and to arrange matters so that the same numerical code element changes at both points may put such severe restrictions upon the code that de-coding it becomes excessively complicated. Here, a simpler solution may be arrived at by using two elements for the sign. Let us call these elements x and y and for an example let the plate be required to indicate degrees. About the zero, the following arrangement is used: X002, X001, 000, Y001, Y002. Here, in the numerical part one code element changes from X001 to 000 and then changes back from 000 to Y001. If in the coding on the plate we invert the numerical element that changes from X001 to 000 and back from 000 to Y001 the result will be that only x and y will change between X001 and Y001 and the progressive nature of the coding will be preserved. Once again, decoding is simple; when x and y are both *absent* the specified element is first inverted. At the opposite side of the circular plate, let the coding be X178, X179, XY180, Y179, Y178. Here, the numerical element that changes (most probably a different one) is inverted in the coding and de-coding when x and y are both present.

This work was carried out as part of the research programme of the National Physical Laboratory, and this note is published by permission of the Director.

REFERENCES

(1) Foss, F. A. *Trans Inst. Radio Engrs*, 1954, EC-3, p. 1
(1954).
(2) Nettell, D. F. *Instrument Practice*, **10**, p. 128 (1956).

Laboratory and workshop notes

A stabilizer for large sub-standard lamps

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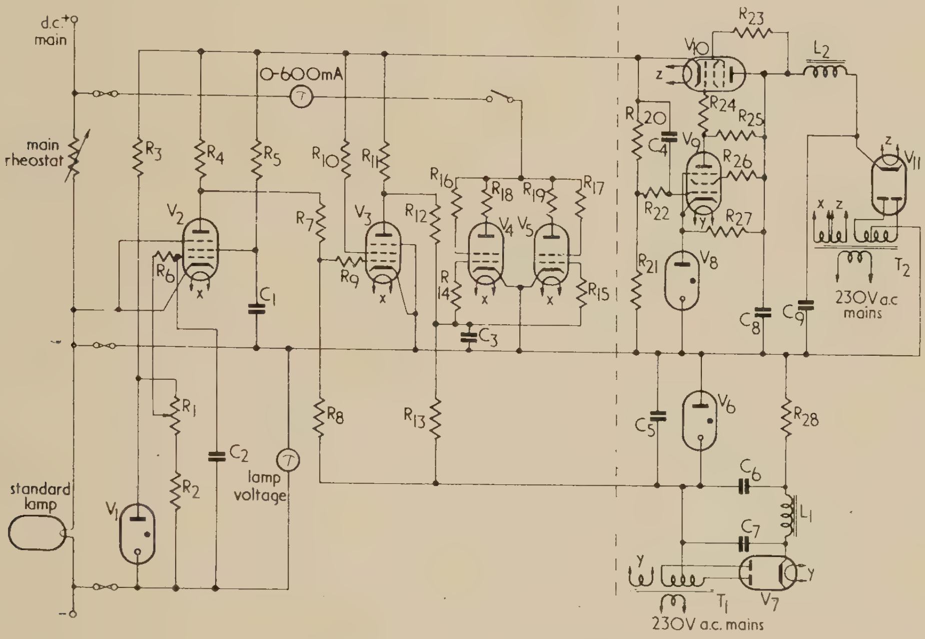
ote *first received* 13 *May, and in final form* 13 *September*, 1957]

hotometric work it is often necessary to run large tungsten ps at constant voltage, and a stabilizer has been developed this purpose. The circuit differs chiefly from those used viously,* in being controlled only from the output side, hat it is suitable for lamps of widely differing types. The ent capacity is also larger than is usual with electronic ilizers.

n practice this stabilizer will maintain the voltage of a W, 100 V projector lamp, running at a colour temperature 2854° K constant to within ±0·01 V over periods of nty minutes or more, and to within ±0·05 V indefinitely. output impedance is less than 0·1 Ω, and in the example ted the stabilization ratio is about 1000.

he circuit as shown will supply lamps in the range 57–85 V, by modifying the reference voltage circuit (R_1, R_2) the ge 5–85 V can be accommodated. The current range is cient to deal with lamps taking up to 10 A, but could be extended by putting more power valves in parallel with V_4 and V_5. The extent of mains variations which can be reliably handled depends on the load, and in the case quoted a peak-to-peak variation of 25 V can be tolerated. Rectified a.c. with rudimentary smoothing could be used instead of d.c.

This work has been carried out as part of the research programme of the National Physical Laboratory, and this note is published by permission of the Director.



Complete circuit of stabilizer

R_1 = 10 kΩ, w.w.
R_2 = 22 kΩ, w.w.
R_3 = 28 kΩ
R_4 = 22 kΩ
R_5 = 2·7 kΩ
R_6 = 22 kΩ
R_7, R_8 = 100 kΩ
R_9 = 10 kΩ
R_{10} = 1·8 kΩ
R_{11} = 15 kΩ
R_{12}, R_{13} = 100 kΩ
R_{14}, R_{15} = 2·2 kΩ

R_{16}, R_{17} = 330 Ω
R_{18}, R_{19} = 23 Ω
R_{20} = 222 kΩ, w.w.
R_{21} = 100 kΩ, w.w.
R_{22} = 470 kΩ
R_{23} = 150 Ω
R_{24} = 1 kΩ
R_{25} = 51 kΩ
R_{26} = 33 kΩ
R_{27} = 330 kΩ
R_{28} = 13·4 kΩ

C_1 = 0·003 μF
C_2 = 0·001 μF
C_3 = 0·004 μF
C_4 = 0·01 μF
C_5 = 0·5 μF
C_6 = 8 μF
C_7 = 4μF
C_8 = 8 μF
C_9 = 4 μF

V_1 = CV 449 (85 A2)
V_2, V_3 = CV 138 (EF 91)
V_4, V_5 = CV 345 (12 E1)

V_6 = CV 2225
V_7 = CV 493 (6X4)
V_8 = CV 449 (85 A2)
V_9 = CV 138 (EF 91)
V_{10} = CV 1862 (EL 90)
V_{11} = CV 493 (6X4)

T_1 = 250–0–250V
T_2 = 350–0–350V

L_1 = 20H
L_2 = 10H

HERCOCK, R. J. *J. Sci. Instrum.*, **25**, p. 320 (1948).
NEALE, D. M. *J. Brit. Instn Radio Engrs*, **15**, p. 271 (May 1955).

A precise reference inductor

By D. GUGAN, B.Sc., Ph.D., Queen Mary College, University of London*

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In the course of some precise magnetic measurements(1) it was found that variations in the atmospheric conditions can cause quite large changes in the calibrations of commercial inductors; these changes, several parts in 10^3, are about one hundred times larger than the temperature and humidity effects found by Rayner and Ford in their study of the N.P.L. precision inductors.(2) Some results obtained using a commercial Campbell variable mutual inductor are briefly reported here, together with a convenient standardizing device which can be used to correct for these changes.

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Ballistic measurements were made by reversing simultaneously two accurately monitored magnetizing currents flowing in the primary windings of a ring of ferromagnetic material and of the mutual inductor respectively. The e.m.f.'s induced in the secondary windings were fed in series opposition to a low resistance, sensitive, long-period galvanometer and the value of the mutual inductance necessary to give a net null deflexion was found. This balance could be made to about 2 parts in 10^5. Balance inductances were found for two quite different magnetic materials, H.C.R. alloy (a grain-oriented, 48% nickel–iron alloy made by the Telegraph Construction and Maintenance Co. Ltd.) and Permalloy F (a domain-oriented, 64% nickel–iron alloy made by Standard Telephones and Cables Ltd.), which were always measured under the same magnetizing conditions.

For many different conditions of the mutual inductor (caused, however, only by the day-to-day variations in the laboratory conditions) it was found that although the mutual inductance needed to balance either of the coils varied considerably, the ratio of the two balancing inductances remained constant within the limits of the experimental error. Because the two magnetic materials were quite different, this implies first, that the variations were actually in the mutual inductor and not in the magnetic materials, and second, that these materials have highly stable properties over a period of at least some weeks. The changes occurring in the inductor were a linear change with temperature of about 3 parts in 10^4 per °C, and a more or less random change of extreme magnitude 2 in 10^3. This second change is most probably associated with humidity variations, the apparent randomness arising from the fact that, as Rayner and Ford have shown, a fairly long characteristic time is involved in these changes. It should be emphasized that the humidity effects occurred in an instrument with waxed coils and apparently protected from such changes. The possibility that leakage currents between the primary and secondary circuits were responsible for these effects is quite ruled out by the fact that the insulation resistance between the circuits was never so low that such effects could be observed. This was known from frequent direct measurements of the insulation resistance and could also be inferred from the movement of the galvanometer spot at each balance setting. The only other places where significant leakage was possible were within the primary and secondary windings of the inductor. If such leakage currents existed and if, in spite of the coils being waxed, they could vary, it might be argued that this does not properly constitute a variation of inductor calibration; as far as the user is concerned, however, the observed effect would be the same as if it did.

It is suggested that in cases where these variations cannot easily be controlled by enclosing the mutual inductor, it may sometimes be convenient to use such ferromagnetic materials as *reference* mutual inductors with which the inductor calibration can easily be checked. By using small, ring-shaped specimens it is possible to obtain magnetizing fields of about 30 oe. for magnetizing currents of about 0·3 amp.; under these conditions the magnetization attained in H.C.R. alloy is within a few per cent of its saturation value, and the variation of magnetization with field is very slow, only about 0·02% for a 1% variation of magnetizing current. Used under these conditions, and at constant temperature, a much larger and intrinsically more stable output is given by such an inductor than is given by an air-cored mutual inductor of similar size. By working in the saturation region most of the difficulties associated with using ferromagnetic materials in mutual inductors are avoided and it has been found that highly reproducible output can easily be obtained.

The author wishes to thank Professor G. O. Jones for h interest in this work, the Department of Scientific an Industrial Research for the award of a maintenance allowanc and the Central Research Fund of the University of Londo for the loan of some of the apparatus used.

REFERENCES

(1) Gugan, D. To be published.
(2) Rayner, G. H., and Ford, L. H. *J. Sci. Instrum.*, 27 p. 19 (1950); 33, p. 75 (1956).

Injecting trace impurities into a gas stream

By P. Hersch, Ph.D.,* and J. E. Whittle, The Mond Nickel Co. Ltd., Birmingham 16

[*Note received* 29 *July*, 1957]

In studying certain aspects of corrosion, air pollution, o catalyst poisoning, it is frequently desirable to produce continuous stream of air or other carrier gas which is contaminated with small, constant, but adjustable, proportion of an impurity. The apparatus described in this note provides a convenient method of obtaining, continuously for lo periods, constant concentrations of 10 to 100 volume/milli (v.p.m.) of an impurity in a 100 ml/min gas stream. By sli and simple modification the concentration can be reduced t fractional v.p.m.

In principle, the apparatus consists of a syringe with column of liquid acting as its piston (1). This is driven by pressure differential in the carrier-gas stream, created by mean of restriction of flow (3). The piston moves forward at a ra proportional to the rate of flow of the carrier gas and th concentration of impurity is thus independent of fluctuatio in the flow of gas.

The upper part of the figure shows the simplest applicatio of the principle: the impurity is admitted (or excluded according to position of the three-way tap. In this versio the space (6) at the exit of the tap would have to be infinitesima if delays of admission of the contaminant are to be avoided A nearly instantaneous build-up of the final concentratio level can, however, be achieved by using the more elaborat design shown in the lower part of the figure, in which th three-way tap is supplemented by a mercury cut-off (8). I this modified design the capacity of the burette (2) is increase and re-filling is speeded up, because the viscous liqui piston (1) can be returned through the non-capillary bridge (7 The degree of contamination of the carrier gas can be varie by the choice of the piston liquid and by inserting varyin lengths of nickel wire into the left arm of the liquid-fille U-tube. Fine adjustment can be obtained by varying th length of wire in the capillary gas choke (3). The contaminating gas in the burette (2) must be protected again temperature fluctuations by lagging (9), otherwise the flo of impurity into the carrier gas stream will be temporari disturbed. When admission of the contaminant has bee interrupted for a time, a slight over-pressure builds up in th burette and before re-admission of impurity the buret should be vented for an instant through exit (5).

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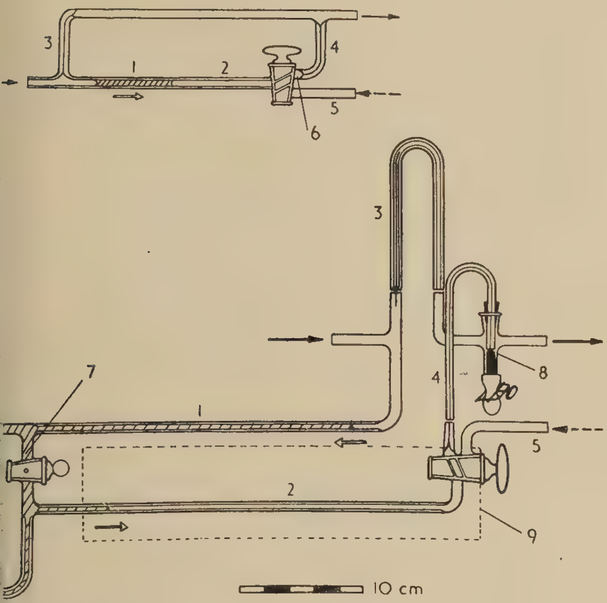
he apparatus has been used, for example, with a mixture volume glycerine plus 3 volume water as piston liquid, ream of 100 ml/min of highly purified nitrogen as carrier and air as contaminant, adjusted to 6 v.p.m. oxygen 03% air) as impurity. The concentration of oxygen measured galvanically.† After operating the three-way and the mercury cut-off, a steady state was reached in ut two minutes. The "noise" was within 2% of the sured value and was caused mainly by temperature tuations.



yringe with liquid piston for adding trace impurities to a gas

) liquid piston; (2) burette; (3) capillary choke; (4) thermo-eter capillary, preventing carrier gas from diffusing into urette; (5) inlet for re-fill (and outlet for venting) of burette;) undesirable pocket; (7) bridge, opened during re-filling; (8) mercury cut-off; (9) lagging.

, under the same conditions, dry air had been used as ier gas and air saturated with water vapour at 20° C as taminant, a moisture concentration of 0·7 v.p.m. would e been obtained, corresponding to a dew point of −78° C. ilarly, if air saturated with an organic vapour is used as taminant, a very low concentration of organics can be hed and controlled.

Vhere impurity levels much below 10 v.p.m. are required advisable to inject 10 v.p.m. or more and then destroy a e proportion of it, e.g. to bring the concentration from .p.m. down to 0·1 v.p.m., 99% of the impurity must be removed. To this end the stream of carrier gas leaving the apparatus is divided, by means of two capillaries choked with wires, into two streams in the approximate ratio 99 : 1 and the main stream is led through a purifier bed. The two streams are then reunited. The volume of the purifier, no matter how large, does not cause any time-lag of response after the injection is started or stopped.

It is considered that it may be possible to extend the principle described to the injection of a liquid into a liquid stream.

The author wishes to thank The Mond Nickel Co. Ltd. for permission to publish this note.

Hersch, P. *Instrument Practice*, **11**, pp. 817, 937 (1957).

Grinding hemispheres of germanium and silicon

By D. B. Gasson, Research Laboratory, Associated Electrical Industries Ltd., Aldermaston, Berkshire

[*Note received* 31 *July*, 1957]

For various crystallographic investigations, highly polished spherical surfaces(1, 2) are sometimes required on germanium and silicon monocrystals.

A short length of circular section material was cut from a monocrystalline ingot prepared by the "pulling" technique, so that the length was slightly more than half the diameter. This was stuck concentrically to the end of a smaller-diameter brass bar with Shellac cement of the de Khotinsky type and was then held in the chuck of a small high-speed electric pistol drill. The material was then ground against a normal bench grinder, fitted with water-cooling so that the rotation of grinding wheel and ingot were mutually opposite. The axis of rotation of the pistol drill was swung from in the axis of rotation of the grinding wheel to a little more than 90° to it to gradually develop a roughly ground hemisphere. Contour accuracy was checked at intervals by using a radius gauge to suit the diameter of hemisphere being prepared. Polishing was effected by using progressively finer grades of emery paper held against the rotating hemisphere and finishing either with proprietary metal polish, diamond impregnated cloth or buffing wheel. To develop the required degree of polish on the material close to the axis of rotation, it was found necessary to oscillate the emery paper to compensate for the lack of surface speed. By this means, polished hemispheres from $\frac{3}{8}$ in. to 1 in. in diameter have been satisfactorily prepared with a contour accuracy within 0·010 in. and a high degree of freedom from polishing scratches as revealed by subsequent etching in C.P.4 fluid.(3)

REFERENCES

(1) Whitmore, R. L. *J. Sci. Instrum.*, **31**, p. 223 (1954).
(2) Bond, W. L. *Rev. Sci. Instrum.*, **22**, p. 344 (1951).
(3) Vogel, F. L., Pfann, W. G., Corey, H. E., and Thomas, E. E. *Phys. Rev.*, **90**, p. 489 (1953).

Correspondence

Lattice parameter determination from broad diffraction lines

The method for accurate determination of lattice parameters from broad diffraction lines, advocated by Brotzen and Harman in their note published on p. 247 of the June issue of this *Journal*, requires some comment. The authors base their method on the belief that the Kα doublet must be resolved in order to make a determination of the line position for use in the Bragg equation. They propose a method for resolving the doublet on the assumption that the line profiles will be approximately Gaussian, and then use the peak position of the resolved Kα_1 line and the wavelength of this line from the International Tables as corresponding values of θ and λ in the Bragg equation.

The method is open to several criticisms. The most serious is that the idea underlying the whole procedure, that is that the doublet must be resolved for accurate work, is in error. In actual fact the reverse is true; accurate parameters may not be conveniently obtained by using the peaks of the diffraction lines since the dependence of the peak positions on the instrumental dimensions, slit widths, etc., is a most complicated function of the Bragg angle, and for accurate work corrections for these aberrations must be made. Any method, therefore, based on the separation of lines into their components and measuring the peak positions, will give results which may not be corrected for instrumental displacement of the lines. These corrections may be neglected in work of low accuracy, but are important for work of high accuracy.

A more suitable method for accurate lattice parameter determination is based upon a fundamental property of the centroid of a diffraction line. This may be derived as follows.

We suppose that the profile which would be obtained on a perfect instrument for the given spacing d to be $f(\theta)$; this will correspond to the spectral distribution of the characteristic radiation. We call the instrumental weight function⁽¹⁾ $g(\theta)$; the observed profile $h(\theta)$ is then

$$h(\theta) = \int_{-\infty}^{+\infty} f(\zeta)g(\theta - \zeta)d\zeta \qquad (1)$$

where h, f, and g are normalized for convenience. Consider the abscissa of the centroid of $h(\theta)$ defined by

$$\begin{aligned} < h(\theta) > &= \int_{-\infty}^{+\infty} \theta h(\theta)d\theta \bigg/ \int_{-\infty}^{+\infty} h(\theta)d\theta \\ &= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \theta f(\zeta)g(\theta - \zeta)d\zeta d\theta \qquad (2) \end{aligned}$$

which by a change of variable becomes

$$\begin{aligned} < h(\theta) > &= \int\int (\xi + \zeta)f(\xi)g(\zeta)d\xi d\zeta \qquad (3) \\ &= \int \xi g(\xi)d\xi \int f(\zeta)d\zeta + \int \zeta f(\zeta)d\zeta \int g(\xi)d\xi \\ &= \int_{-\infty}^{+\infty} \xi g(\xi)d\xi + \int_{-\infty}^{+\infty} \zeta f(\zeta)d\zeta \qquad (4) \end{aligned}$$

Thus

$$< h(\theta) > = < g(\theta) > + < f(\theta) > \qquad (5)$$

In the derivation of this result no assumption has been made about the distribution of $f(\theta)$, the spectrum of the radiation, and the property applies equally well to any line, resolved or unresolved doublet, or indeed to the whole spectrum between any specified limits, provided that the weight function of the instrument may be assumed constant between them and that allowance is made for dispersion.⁽²⁾

The property expressed by equation (5) allows truly equivalent values of wavelength and observed line position to be determined for use in the Bragg equation by a very simple procedure, merely, in fact, by subtracting the value of the shift of the centroid due to the instrumental aberrations. This shift has been thoroughly investigated in the literature.⁽³,⁴,⁵⁾ It is found, moreover, that the various instrumental factors shift the position of the centroids of the lines in such a way that a straight line extrapolation against $\cos^2$ may be made to $2\theta = 180°$ to give the corrected lattice spacing. The major error normally removed in this way is the lack of precise knowledge of the position of the surface of the specimen with respect to the axis of rotation of the goniometer.

For very accurate work corrections must be applied to the extrapolated value for the effects of vertical divergence, refraction⁽⁶⁾ and dispersion.⁽²⁾

At the present moment the limitation on absolute accuracy is the lack of precision of current wavelength data. It is not clear whether published values refer to the peaks or centroids of characteristic lines. The grating values may be nearer the latter, and the crystal measurements nearer the former, owing to the different degrees of dispersion in the two experimental procedures. The value of the conversion constant λ_g/λ_s between grating and crystal measurements is still not known as accurately as is desired.

For the unresolved doublet the weighted mean of the wavelengths of the α_1 and α_2 components may be used for the centroid of the spectral distribution. Comparing this with the centroid of the observed profile is preferable to trying to separate the doublet, and there is the added advantage that an estimate of the instrumental shift of the centroid may be made and applied in the first case.

The assumption of a Gaussian profile is hardly valid. Theoretical considerations give a Cauchy or "witch" profile to the spectral distribution and this will be a major cause of broadening in the back reflexion region. In practice, diffraction lines are found to fall off much more slowly than would a Gaussian distribution, and therefore the low intensity points on either side of the line are much more important than would be the case for Gaussian distribution; if in fact the lines were Gaussian, diffractometry would be very much easier, as "background" would be less trouble to deal with.

A further comment on the method used by Brotzen and Harmon concerns the counting time involved in making the determination of the line position. For their method the profile of the line must be known reasonably accurately and hence a fairly large number of quanta must be accumulated at each step to minimize distortions which would arise from the random counting errors. Figures quoted by them are 16000 to 32000 counts at each position, although this number would be far more than sufficient to eliminate significant errors from this cause. The residual fluctuations shown on their figure must be due to other than statistical counting limitations, possibly coarseness of the sample, and the time spent in counting large numbers of quanta would aps have been better employed in further grinding, or ounting smaller numbers of quanta at closer intervals.

or a determination of the centroid, however, the line e, as such, is not of interest; an analytical treatment of statistical error in the determination of the centroid(7) vs that its position may be found accurately with a risingly small number of counts collected at each position. hout knowing the exact conditions of the experiment ted, particularly the background level, an accuracy in position of the centroid equal to that which was obtained ° 2θ) could almost certainly be expected with a *total* ection of quanta over the whole line equal to the number ch were actually counted at one point.

entroids of diffraction lines may be calculated from a list otal (line-plus-background) intensities at equidistant steps g the profile, without plotting, by making use of an nary desk adding machine. The listed intensities are set urn on the right-hand side of the keyboard and added; at same time the accumulated total at each step is set in the hand side of the keyboard so that these are added as well. the end of the line the total on the right-hand side is ded into the total at the left, and the quotient gives the lacement of the centroid of the line-plus-background n the last angle reading, in terms of the step length. The ct of the background is removed by a correction as follows. et the centroids of the total, line, and background areas (T), $G(L)$ and $G(B)$ respectively. We take moments about last point of the line (θ_z) letting the distances from this it of these centroids be t, l, and b, respectively. We see the sum of the sub-totals accumulated on the left-hand of the keyboard above (ΣS) is equal to zero times the intensity reading, plus one times the penultimate, plus e the one before, etc., up to n times the first; thus if we ote integrated intensities by $\mathscr{I}$,

$$\Sigma S \Delta\theta = \mathscr{I}_T t \tag{6}$$

re $\Delta\theta$ is the step length.

ow

$$\mathscr{I}_T t = \mathscr{I}_L l + \mathscr{I}_B b \tag{7}$$

if a is the average of the first, say, five intensity readings, z that of the last five, on inserting the value of b for the ezoidal background area,

$$\Sigma S \Delta\theta = (\mathscr{I}_T - \mathscr{I}_B) l + \mathscr{I}_B \left[\frac{n\Delta\theta}{3} \left(\frac{2a+z}{a+z} \right) + \frac{\Delta\theta}{2} \right] \tag{8}$$

re n is the total number of steps.

we write

$$r = \mathscr{I}_B / \mathscr{I}_T,\ \delta = (z-a), \text{ and } B = \tfrac{1}{2}(a+z) \tag{9}$$

ation (7) gives

$$L) = \theta_z - \left\{ \frac{\Sigma S}{\mathscr{I}_T} + \frac{r}{1-r} \left[\frac{\Sigma S}{\mathscr{I}_T} - n \left(\tfrac{1}{2} + \frac{1}{2n} - \frac{\delta}{12B} \right) \right] \right\} \Delta\theta \tag{10}$$

the background has a negligible slope, the correction reduces to

$$\frac{r}{1-r} \left(\frac{\Sigma S}{\mathscr{I}_T} - \frac{n}{2} - \tfrac{1}{2} \right)$$

he centroid may be determined, according to the number teps, in something over five minutes without the background correction; this correction takes a few minutes more multiplying machine.

o avoid errors due to the slow approach of the profile e background it should be arranged that the limits taken are as nearly symmetrical about the corrected centroid as possible.(7)

Viriamu Jones Laboratory,
University College,
Cardiff.

E. R. PIKE

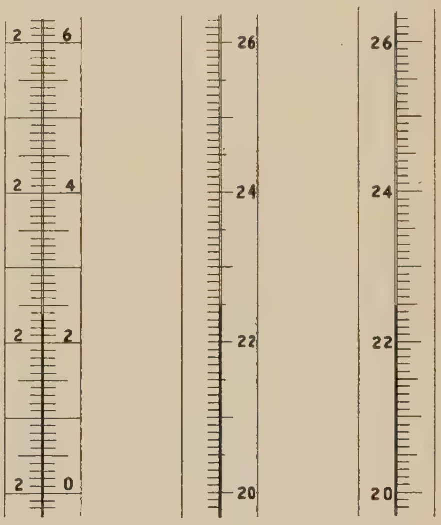
[23 *July*, 1957]

REFERENCES

(1) SPENCER, R. C. *Phys. Rev.*, **55**, p. 239 (1939).
(2) LANG, A. R. *J. Appl. Phys.*, **27**, p. 485 (1956).
(3) WILSON, A. J. C. *J. Sci. Instrum.*, **27**, p. 321 (1950).
(4) PARRISH, W., and WILSON, A. J. C. *Acta Cryst.*, **7**, p. 627 (1954).
(5) PIKE, E. R. *J. Sci. Instrum.*, **34**, p. 355 (1957).
(6) WILSON, A. J. C. *Proc. Cambridge Phil. Soc.*, **36**, p. 485 (1940).
(7) PIKE, E. R., WILSON, A. J. C., and HUGHES, J. W. *The measurement of line positions and intensities for the A.S.T.M. X-ray Powder Data File.* Circulated 1957 and presented at the Montreal Congress of the International Union of Crystallography.

A scale for solid-stem thermometers

Two styles of scale are in general use for mercury thermometers: Fig. 1 shows that preferred in Germany and Fig. 2 is the usual English style. The German dividing is best suited for enclosed-scale thermometers, where the scale is placed behind the mercury column, but it has the disadvantage of periodically obscuring the meniscus behind the graduation lines when it is applied to a solid-stem thermometer. The English style of dividing partially avoids this trouble, but the column is still obscured by the longer graduations, and it is suggested that the style shown in Fig. 3 affords a better solution.



(1) (2) (3)

Fig. 1. Enclosed scale (German style); Fig. 2. Solid stem (English style); Fig. 3. Solid stem (suggested style)

The suggested style offers the following advantages:

(*a*) the mercury column remains uncovered by graduation lines or figures along the full length of the scale;

(*b*) the units of the figures remain in the field of vision, i.e. close to the mercury column. When the figuring consists of two-figure and three-figure numbers, it is necessary in precision reading to recognize first of all the right-hand figure, but the unit figure is only clearly visible when the figuring is placed at the left-hand side of the mercury column;

(*c*) as the uniform ends of the graduation lines touch the mercury column, interpolation is easier;

(*d*) a suitable illumination of the scale will cause a reflexion of the graduation lines in the mercury column. By alineing these reflected lines and the actual graduation lines, parallax errors may be excluded.

All figures should be applied only in narrow lettering and in a vertical position parallel to the axis of the thermometer, with a height of 1·5 to 2 scale intervals and with their centre intersected by an imaginary prolongation of the graduation line to which the figure is allotted. In this case the figures distinctly emphasize the figured graduation lines. If the figure zero is made rather narrow the previous figure of the number will be sufficiently recognizable even if the thermometer is of small diameter.

The graduation lines should be made very short, i.e. not longer than 1/20 of the circumference (about 1 mm) but at least as long as one interval of the scale. The second length of the graduation lines should be not longer than 1·5 times and the third length not longer than 2·5 times the length of the shortest lines. In most cases two lengths of graduation lines will be sufficient if figuring is used to emphasize those lines for which a third length would otherwise be required. For precision reading a line length of 1 mm is sufficient. Even for the control of the parallax by means of the reflexion of all graduation lines on the mercury column, lines of 1 mm length are satisfactory when properly illuminated from the right-hand side. If the lines are too long the variations in length will be outside the field of vision.

Deutsches Amt für Material und
Warenprüfung, E. Greil
Ilmenau, [2 October, 1957]
Germany.

The a.c. properties of resistors

In the May 1957 issue of this *Journal* Messrs. Rayner and Ford state* that radio-type carbon composition resistors are non-reactive in values around 30 Ω. This is correct if there is approximate numerical equality between the inductance expressed in e.m.u. and the capacitance expressed in e.s.u. Such equality could be achieved in a resistor whose two terminals are very close together and in which the current flowing along the resistor returns by a coaxial sheath around it (a desirable though unusual arrangement for resistors of the order of 30 Ω). In most practical cases, however, the inductance in e.m.u. will be many times greater than the capacitance in e.s.u., and the value of resistance leading to non-reactive properties will be larger—often, I suggest, of the order of 1000 Ω.

Post Office Engineering Research Station, A. C. Lynch
Dollis Hill, [30 July, 1957]
London.

The statement Mr. Lynch refers to had its origin in a suggestion he himself put forward (see Ref. 2 of our paper). To resolve the matter and because the characteristics of carbon resistors are of some general interest the authors have looked more closely into their time constant. A detailed account is being prepared and we give below a summary its conclusions.

The shunt capacitance of a small solid carbon-compositio resistor with a ceramic sleeve is about 0·6 μμF at audi frequencies, and its inductance is about 0·007 μH. Thus th time constant is zero for nearly all practical purposes (it wi be less than 1×10^{-9} in magnitude) for resistance valu between 10 Ω and 1000 Ω and it will be very close indeed zero for a value of 100 Ω. A 30 Ω resistor will have a tim constant of about $+2 \times 10^{-10}$, and a 1000 Ω resistor one about -6×10^{-10}.

Electricity Division, G. H. Rayner
National Physical Laboratory, L. H. Ford
Teddington, [26 August, 195
Middlesex.

A method of preparing and filling plastic tubes for specimens for X-ray powder photographs

Lonsdale and Smith(1) describe a method of preparing plast tubes to contain specimens for X-ray powder photograp An annealed copper wire is coated by dipping in a solutio of Cellophane in 1 : 1 acetone/amyl acetate; when dry, th tube so formed is removed by stretching the wire and wit drawing it. This method has been widely adopted,(2–5) wit modifications mainly in the method of preparing the wir and the use of alternative plastics. Recently Thomas an Alexander(6) found that tubes of Parlodion were more readil stripped from copper wire that had a coating of cuprous oxi they described a method of annealing the wire for this purp for ninety minutes in a stream of wet nitrogen. Method of filling the tube have also been described, which all invo handling and possibly deforming it. The following meth of preparing and filling specimen tubes is rapid and easy apply, giving true cylindrical thin-walled tubes (0·01–0·02 m wall thickness).

The whole of a suitable length of high conductivity coppe wire is annealed at red heat by drawing it slowly throug gas flame. A little practice eliminates any tendency to me the wire. About three inches of the wire at one end is brough to red heat and at once quenched briefly in concentrate hydrochloric acid which has been diluted with about ha its volume of water. A continuous adherent red coating formed, identified as cuprous oxide by X-ray diffraction.

A glass tube is drawn down at one end to an interna diameter just greater than that of the wire. The wire inserted in the tube with the coated end protruding one two inches, and held there by winding the excess wire roun the top of the tube. The protruding wire is dipped into thin solution of plastic to submerge the drawn end of th tube, and withdrawn slowly and vertically to give an eve coating of plastic on the wire. The joint between wire an glass tube is reinforced by a collar of thicker plastic solutio and the assembly is dried in a vertical position.

When dry, the tip of the coated end of the wire is scrap free from plastic and held in a vice. When the excess wire gripped and pulled, it stretches, parts cleanly from the plast and can be withdrawn. The plastic tube so formed is attache to the glass by which it can be handled. It is freed fro cuprous oxide by flushing with dilute hydrochloric aci dried in air and sealed by dipping the tip in thick plast solution.

The glass tube forms a convenient funnel for filling with th required powder. This can be tamped with a thinner wir if desired. Alternatively, the glass tube is attached to on end of a thin steel strip, the other end of which is fixed.

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* Rayner, G. H., and Ford, L. H. *J. Sci. Instrum.*, **34**, p. 190 (1957).

trip vibrates naturally at relatively high frequency and amplitude the powder readily packs evenly into the men tube. This method is particularly convenient to n a dry-box.

e tube is cut away and the cut end is sealed with thick ic solution. It may be held by tweezers above the ed length of the specimen. Alternatively, to avoid rmation the tube can be plugged with the same copper or other inert close-fitting rod, moistened with thin ic solution. The specimen is then cut away with wirers.

e confirm that a cuprous oxide coating enables the wire irt from the plastic more readily, as claimed by Thomas Alexander, and have found no difficulty in obtaining a ble coating by the above rapid method. Specimen tubes be made individually by our method, but the very short ig time and easy filling procedure offer a decided advan- We have successfully used solutions of Perspex in oform, and Cellophane in amyl acetate, with drying s not more than a half and one hour respectively.

Thanks are due to the North Thames Gas Board for permission to publish this note.

North Thames Gas Board,
Fulham Research Laboratories,
London, S.W.6.

W. E. Armstrong
R. J. Davis

[8 August, 1957]

REFERENCES

(1) Lonsdale, K., and Smith, H. *J. Sci. Instrum.*, **18**, p. 133 (1941).
(2) Burr, A. A. *Rev. Sci. Instrum.*, **13**, p. 137 (1942).
(3) Ness, R. K. *Rev. Sci. Instrum.*, **17**, p. 344 (1946).
(4) Wait, J. M. *Rev. Sci. Instrum.*, **17**, p. 557 (1946).
(5) Beu, K. E., and Classen, H. H. *Rev. Sci. Instrum.*, **19**, p. 179 (1948).
(6) Thomas, L. R., and Alexander, L. E. *Rev. Sci. Instrum.*, **27**, p. 174 (1956).
(7) See Klug, H. P., and Alexander, L. E. *X-Ray Diffraction Procedures*, pp. 199–201 (London: Chapman and Hall, Ltd., 1954).

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ucts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

y diffraction camera. N. V. Nederlandsche Röntgen-Apparatenfabriek, Delft, Holland.

crystallographic camera utilizes the well-known Guinier ciple of focusing whereby the camera is achromatized ie Kα_1 and Kα_2 lines. The advantage is twofold: diffrac- lines are sharp and single in by far the greater part of pattern, while maximum sharpness is centred about = 30° which is often also the centre of the most interesting on. The relatively unsatisfactory range where the Kα-blet is on the verge of being resolved, which in the best ye–Scherrer cameras just about covers this centre, is ed to a much less disturbing value ($2\Theta = 70°$).

ie range covered by the film is from 0–90° (or 0–45° in g angle) in the present camera. The sacrifice of higher e diffraction lines has been made for several reasons. , it is impossible with the Guinier method to cover the e range with a single exposure because of the limits set ie angle of incidence on the film. Second, a fixed range vs a simple construction of the quadruple camera, which ld otherwise not be the case. Third, the advantages of Guinier method are much more useful in the low- and ium-angle range than in the back-reflexion range. More- , the loss of the back-reflexion range is rarely felt as a e one because of the gain in resolving power which the nier camera offers when compared with conventional ye–Scherrer cameras.

ill use is made of the aperture of the monochromatized n by mounting four specimens in a vertical row. Accord- the film cassette is divided in four sections by three ens.

ie four patterns are each 8 mm high, with 1 mm in een. With identical samples there is no difference in width between the middle and outer patterns; only a t tilt can be observed for diffraction lines with $2\Theta = 70°$ above in the outer patterns. This effect is, however, harmless provided standard conditions are set up for precision measurement of Θ. Such measurements are facilitated by knife edges in the lower and upper rim of the camera.

The quartz crystal is a plane parallel slab 50 × 20 mm, cut at an angle of $4\frac{1}{2}°$ with the (1011) lattice plane which is used for reflexion.

With a quartz centre-focal line distance of 220 mm the optimum distance of the focal spot to the quartz centre is only 110 mm for copper Kα, so that energy losses are minimized. The crystal is bent by applying two torques at the short edges, the amount of these torques being controlled by two adjustment screws. Excellent focusing is said to be obtained over the entire height of the focal line by using a simple visual adjusting method.

The above-mentioned quartz slab can be used for wavelengths upwards from 1 Å. A special quartz slab cut at 2° with the reflecting planes can be provided if the use of Mo-radiation is desired.

Details of performance:

Camera diameter	114·6 mm
Equivalent Debye–Scherrer camera diameter	229·2 mm
Dispersion, per degree of Bragg angle	4 mm°
Useful aperture of convergent primary beam, up to	3°
Height of each of the 4 specimens	4 mm
Useful width of each of the 4 specimens, up to	6 mm
Film size	180 × 43 mm

The samples are prepared in four rectangular apertures of a thin plate, either by their own cohesion or mounted on films or cellophane, etc. When filled, the plate is placed in the removable sample holder, and the latter is inserted in the camera. It may either be locked, or given a rocking motion in its own plane. A vertical shield within the camera minimizes air scattering. The remaining contribution of air scattering is small. Complete elimination is obtainable by using the vacuum hood. This hood covers only the cassette, leaving free a space behind the monochromator in which the crystal-reflected beam can easily be observed. Hence re-adjustment of the camera with respect to the X-ray tube is possible even during the exposure without touching the evacuated part.

Equipment for processing and drying 35 mm film. Kodak Ltd., Kodak House, Kingsway, London, W.C.2.

The new Kodak 35 mm spiral film processing outfit model 100 and the companion Kodak spiral film drier model 100 have been designed to facilitate the processing and drying of 35 mm film, perforated and unperforated. The spool will accept 100-ft lengths of film together with the integral leader and trailer which is included when the film is supplied on daylight loading spools.

The 35 mm spiral film processing outfit model 100 is said to provide a simple and reliable method of winding the film into a spool of the spiral groove type. Loading of the film into the spiral spool is simple; the chute on the film housing guides the film directly into the grooves. The spiral cheeks of the spool are made of rigid plastic material and the grooves are undercut to form a natural guide for the entry of the film. Only a narrow edge comes into contact with the film, thus ensuring efficient overall processing and drying. When the outfit is used in conjunction with the spiral film drier, processing can be carried out from start to finish without handling the film at any stage after the free end has been attached to the spool, by means of the clip provided.

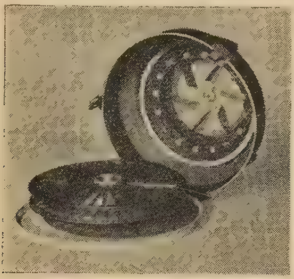


Fig. 1. 35 mm film processing outfit model 100

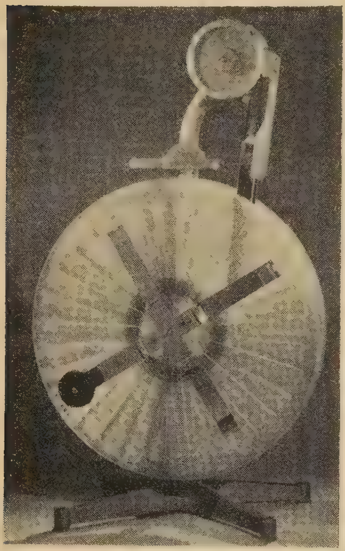


Fig. 2. Spiral film drier model 100

An efficient, safe and rapid method of drying the processed film is said to be provided by the Kodak spiral film drier model 100 (Fig. 2). The drier consists of a conical housing containing a heater and a combined electric moto and fan which is placed over the spiral spool. When the curren is switched on, the resulting flow of warm air rotates the spoo and distributes a constant flow of warm air over the entire surface of the film.

Mass spectrometers for analysis of inorganic solids. Metropolitan-Vickers Electrical Co. Ltd., Trafford Park Manchester 17.

The MS5 mass spectrometer has been designed for the determination of isotope ratios using the surface ionization technique. The solid sample, in the form of a salt such as the nitrate or sulphate, is painted directly on to the surface of a tungsten filament. When the filament is heated, positive ions are emitted directly from the surface and are identified and measured by conventional mass spectrometric techniques. The surface ionization technique is well adapted to the measurement of isotope ratios, but is not so suitable for the general analysis of solids because different elements have widely different sensitivities. The MS5 spectrometer is therefore specifically designed for isotope ratio measurements. The instrument uses a 12 in radius 90° single-focusing magnetic field with either single or triple filament surface ionization technique. A sliding bar vacuum lock enables the sample to be introduced into the instrument in less than a minute. The collector system is arranged so that a normal collector with a noise level of 3×10^{-15} A, or an electron multiplier with an equivalent noise level of less than 10^{-18} A, can be switched into circuit. A resolving power of at least 300 is claimed. Nearly 75% of all elements respond to the surface ionization technique, including most metallic elements. The normal size of a sample is a few μg, but with certain elements 10^{-11}g will enable approximate determinations of isotope ratio to be carried out. The time required for an analysis varies from 10 min to 1 h, depending on the element and the sample size available.

The MS7 mass spectrometer uses a vacuum spark as an ion source. The large energy spread in the ion beam makes it necessary to use a double focusing Mattauch type instrument. It is stated that one of the most promising applications of the instrument is in the analysis of impurities in solids. A photographic plate is used as an integrating device, and a series of exposures of gradually increasing length are taken by means of a rack mechanism which allows up to 10 exposures to be recorded on the same plate. The exposure is accurately determined by the total integrated charge falling on a monitor collector. The concentration of impurity is estimated from the intensity of the lines on the longer exposures, and with this technique, concentrations down to 0·1 p.p.m. can be estimated. The whole mass range from 7 to 240, covering all elements, can be recorded in a single exposure of the photographic plate.

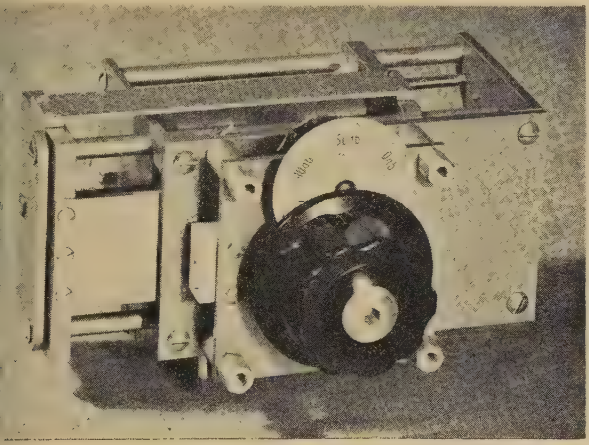
Temperature recorder. Bailey Meters and Controls Ltd., Purley Way, Croydon, Surrey.

The recorder is of the moving-coil galvanometer type, with a chopper bar mechanism. The galvanometer has a sensitivity the ½ in/mV. It utilizes a formerless coil to reduce inertia and minimize response time; an Alcomax III magnet with sintered pole-pieces; spring-mounted jewel bearings; and control springs working in opposition to avoid zero drift. A four-position double-pole wiping contact switch is used to select in turn the signal from each of four stations. The switch is operated by a Geneva movement at a change-over rate of 30 s. The selected signal is fed into the galvanometer

synchronized with movements of the ribbon frame and
)per bar so that the signal from each station is printed
's own distinctive colour. The chart is driven by a syn-
nous motor giving a standard chart speed of 1 in/h
can be modified to ½ or 2 in/h). The chart has a cali-
ed width of 5 in and is supplied in rolls which, at the
idard speed, have a life of 30 days continuous operation.
instrument can be used with chromel/alumel or plati-
ı/platinum–rhodium thermocouples, or with resistance
mometers. The charts can be supplied to cover a variety
emperature ranges from 0/250 to 0/1500° C, or the
valent in Fahrenheit readings.

ret type attenuator. Advance Components Ltd., Roebuck
Road, Hainault, Ilford, Essex.

type A63 attenuator is a completely coaxial attenuator
covering the frequency range zero to 3000 M/cs. It has
oaxially constructed resistive pads which are selected by
ting the control knob. The attenuation of the pad selected
dicated by a figure which appears on a dial geared to the
rol. The section is made by a mechanical linkage system
h unplugs the coaxial connexions to a pad, rotates the
et to the desired position and plugs into the pad selected



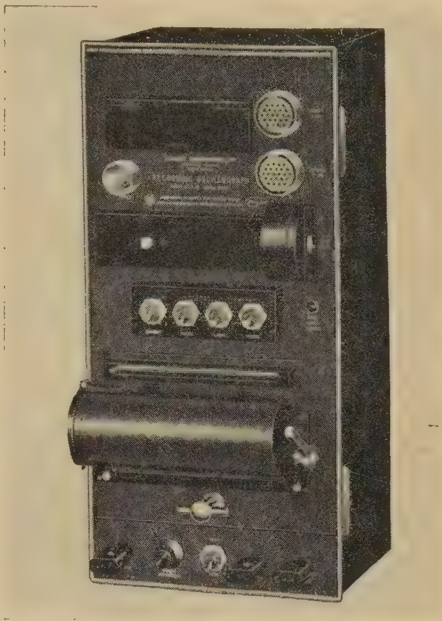
Turret type coaxial attenuator

ı only one rotary movement of the control knob. The
ice may be fitted with any combination of pads from
50 dB in 10 dB steps. The input and output impedances
both 75 Ω and the attenuator is designed to accept
idard Plessey Minor coaxial fittings. The instrument is
able of handling up to 1 W of sine-wave power. In
rply pulsed conditions, its rating is limited by the peak
age of the signal. The limit of this voltage is of the order
100 V for pulses of a few μs duration. A maximum
nuation of 50 dB is recommended at 3000 Mc/s, but this
be extended at lower frequencies. An attenuation
uracy of ±1 dB up to 1000 Mc/s is claimed. The tem-
ature coefficient is of the order of 0·005 dB/° C.

enty-five channel recording oscillograph. Seismic Instru-
ments Ltd., Granta Works, Cambridge.

BER–62 oscillograph was designed for seismic explora-
ı work, but has applications in other fields of research.
ecords signals in the frequency range zero to 100 c/s
tographically on 25 independent traces. Time-marking
s appear across the record every 10 ms, every fifth line
ıg heavy as an aid in computing. The oscillograph is

built to withstand rough use in the field with a minimum of maintenance. The chassis is constructed of black anodised aluminium housed in a robust stainless steel case. The 25 "pencil" galvanometers plug into a single magnetic block. Each element has a natural frequency of 125 c/s and is fitted with a 11 in. radius mirror of size 0·218 × 0·035 in. The



Twenty-five channel recording oscillograph.

current sensitivity of the 13 Ω coil is 4 in./mA at 12 in. Each of the 25 elements is insulated from the others and can be independently adjusted. They are carefully matched in both natural frequency and sensitivity, making possible accurate measurements of phase difference between two similar signals. Before sealing, the elements are filled with dry nitrogen to ensure long and reliable life. All the components of the optical system are readily accessible, and once adjusted seldom need touching again. The optical system is claimed to give a high resolution. A synchronous motor driven by a temperature-compensated valve-maintained tuning fork provides a timing accuracy of 0·02%. All the electronic components are sealed in a plug-in container to simplify field servicing, and the use of "trustworthy" valves is said to make the system thoroughly reliable. The daylight-loading paper storage magazine holds 150 ft. of 6 in. medium weight paper. A paper knife is built into the receiving magazine and acts as a light seal when closed. The paper speed is held constant within close limits by a governor-controlled motor and can be adjusted from 10 to 15 in./sec. Other speeds are possible to special order.

Spectrophotometer. Optica United Kingdom Ltd., A7, Team Valley, Gateshead on Tyne 11.

The CF 4 Spectrophotometer incorporates a grating which offers the advantages of uniform dispersion throughout the entire working range, high light efficiency and exceptional resolution, and enables narrow and constant bandwidths to be obtained, not only in the ultra-violet, but also in the visible and near infra-red regions.

The monochromator of the CF 4 comprises a mirror monochromator with a concave collimating mirror of 800 mm focal length and a free diameter of 80 mm, a plane grating and coupled entrance and exit slits of 20 mm height, which may be adjusted to an accuracy of 0·01 mm. The range of the standard monochromator extends from 1850–10 000 Å and the wavelength scale of 1 m is so arranged that at any point within the range, intervals of 5 Å can be read directly and much smaller intervals estimated. The dispersion is 16 Å/mm.

For measurements in the region 3200–10 000 Å, a 12 V, 60 W tungsten lamp is used, which is connected to the mains power supply through a stabilizer. For work in the ultra-violet region 1850–4000 Å, a hydrogen lamp is used, which is also supplied from the mains through a stabilizer. Both sources may be brought into the light path by a simple sideways displacement of the housing, which contains both sources, along a precision guide rod.

The receiver is a photomultiplier, ensuring high sensitivity. The output from the photomultiplier is coupled to a valve voltmeter and balance is obtained by means of a precision potentiometer, which is coupled directly to the transmission and extinction scales. The measuring accuracy is said to be 0·15% or better at any point of the scale.

Any cells of 12 mm width and 45 mm height can be used, with absorption paths up to 40 mm in the standard instrument. Path lengths of up to one metre can be obtained by means of a special attachment. Heated and flow-through cells can also be supplied. Up to four cells can be fitted into the cell holder.

Accessories are available which can be added at any time. These include a nephelometry attachment for solutions with which measurements can be carried out with white or monochromatic light, a fluorescence attachment for solutions using an ultra-violet beam of low intensity, a flame attachment of high sensitivity using a high pressure acetylene/oxygen or hydrogen/oxygen burner, a reflexion attachment for opaque materials designed in accordance with C.I.E. recommendations, a pen recorder and a double-beam attachment. The double beam attachment allows direct comparison to be made of the absorption of the solution to be analysed and that of the solvent.

Eyepiece camera for photomicrography. W. Watson and Sons Ltd., 313 High Holborn, London, W.C.1.

This camera has been developed for the use of the microscopist who wishes to record photographically what is seen without disturbing the set-up of the microscope. The equipment consists of an adapter, a prism housing, a viewing means and a camera body. The adaptor fits on to the microscope eyepiece tube and is clamped firmly into position by means of a thumb screw. If it is left on the microscope, it will not in anyway interfere with the use of the microscope for normal work. The prism housing carries a partially silvered prism which divides the image-forming beam from the microscope into two parts, directing one part of the light to the viewing eyepiece, and the other part through the prism to the photographic plate or film. A camera shutter operated by cable release is fitted into the top end of the housing, and this is speeded to give exposures of time and bulb, 1 s, $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{25}$, $\frac{1}{50}$, $\frac{1}{100}$ and $\frac{1}{250}$ s, operated by cable release. The viewing eyepiece attaches to the face of the housing by a quick release catch. The eyepiece has a spiral focusing motion and is fitted with a graticule defining the limits of field for both 35 mm film and $3\frac{1}{2} \times 2\frac{1}{2}$ in. plates. The viewing screen can be used in place of, or as an alternative to, the viewing eyepiece. The image is projected on to an etched glass screen, which is ruled to show the 35 mm frame or the area of the $3\frac{1}{2} \times 2\frac{1}{2}$ in. plate which will be exposed.

The plate camera body clamps into the housing immediately above the camera shutter. It is fitted for a single metal plate holder for $3\frac{1}{2} \times 2\frac{1}{2}$ in. plates and two plate holders are supplied with the camera; these can be used for flat films in an adapter if desired. The film camera body clamps into the housing in the same way as the plate camera body. The film camera will take the standard 35 mm film in 36-exposure cassettes and the film winding mechanism is fitted with an automatic stop movement eliminating wasted frames. Short lengths of 35 mm film may also be loaded for single exposures. A light-tight shutter slide is provided for the camera to allow removal of the camera body from the microscope without exposing any of the loaded film. For the microscopist who desires to use his own Leica camera body, an adapter ring is supplied that fits into the prism housing; the other end of the adapter will screw into the Leica lens flange.

The prism housing has built in a correcting lens fitted above the prism, and immediately below the shutter. This lens maintains the correct tube length when a 35 mm camera body is used; when the $3\frac{1}{2} \times 2\frac{1}{2}$ in. plate holder is used it also carries a built-in correction lens which, in conjunction with the lens fitted in the prism housing, again maintains correct tube length. Interchange of the 35 mm camera and the $3\frac{1}{2} \times 2\frac{1}{2}$ in. plate camera body does not alter either tube length or focus. Film plane, plate plane, viewing eyepiece and viewing screen are all in exact register.

British Journal of Applied Physics

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CONFERENCE REPORT

Summarized proceedings of a conference on biological structures and computational methods—London, November 1956. By J. Finch, D. W. Green, K. C. Holmes and A. C. T. North.

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The use of polytetrafluoroethylene as a lubricant. By E. Kay and E. D. Tingle.

A technique for obtaining thin foils of aluminium and aluminium alloys for transmission electron metallography. By R. B. Nicholson, G. Thomas and J. Nutting.

An overall test of equations of state of fluids. By N. Davy and Barbara M. Bell.

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Photoelastic investigation of stresses in composite models with notches and holes. By Heihachi Shimada.

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NOTES AND NEWS

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ORIGINAL CONTRIBUTIONS

New types of recording differential thermobalances

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The paper describes two types of thermobalances which automatically record both the differential and cumulative weight losses during pyrolysis of samples. In both balance systems displacement of the balance beam due to changes in the weight of sample is converted into an electrical signal; the amplified signal operates the servo-mechanism which applies the counterbalancing force at the necessary rate. However, the servo-mechanisms differ in the two types. In one, an analytical balance is adapted so that the sample is counterbalanced by the suspended electrode of a silver coulometer; the controlling current passing through the cell gives a measure of the rate at which the sample loses weight. In the other, a servo-motor rotates the head of a torsion balance to maintain equilibrium; the rate of weight loss is proportional to the speed of the motor and to the voltage applied to it. Alternative control circuits are mentioned. The present torsion-type differential thermobalance can record total weight changes up to 0·5 g at a maximum rate of 30 mg per minute. The cumulative change in weight is registered to the nearest 0·1 mg on the dial counters and 1 mg on the recorder chart; the differential weight change can be read to within 0·2 mg per minute. As the differential weight loss is sensitive to variations in heating rate, a linear-rate controller capable of high accuracy was specially designed for use with the thermobalance.

mogravimetric analysis—the method of following the se of thermal decomposition of a substance by its change eight—has been advanced in recent years by the advent istrumentation. Several types of automatic balances have ı developed which give recorded curves of only the cumu- e weight loss against time or temperature of a sample ımposing under controlled conditions of heating. It is uently necessary, however, to prepare from these records es of the rate of weight loss as a function of time or tem- ture, and this requires application of the relatively curate and lengthy process of graphical differentiation. erential thermobalances enable the decomposition process e more readily followed by registering directly the rate veight loss and thereby avoiding the tedium of manual pretation; the curves produced are comparable with those ined by differential thermal analysis.*

he two new types of differential thermobalances, which described below and in recent patent applications,(1) devised to give, automatically, accurate and continuous rds of instantaneous rate of weight loss together with the l cumulative weight loss. They differ in principle of ration from those already reported by De Keyser(2) and ey and others,(3) the only other known types.

lthough the present balances were primarily developed coal carbonization research, they could find useful application in other fields of work.

PRINCIPLES OF OPERATION AND DESIGN

he balance system, which is essentially the same for both s, has a photocell relay for converting the displacement e beam from its null position into an electromotive force; lectromechanical device converts the electromotive force a proportional mechanical force necessary to restore nce, and a recording potentiometer measures this electroive force. The balance system is thus maintained in a state of continuous equilibrium by a counterbalancing force proportionally controlled by an electromotive force which in turn is equivalent to the rate of weight loss. An important feature of this system is that it is null-point balancing with regard to the rate of weight loss and therefore independent to a large extent of the characteristics of the electrical circuit.

The means of electromechanical linkage differ in the two types. In the original balance system the sample under test was counterbalanced by the suspended electrode of a silver coulometer, balance being maintained by continuous change in weight of the silver electrode due to a control current passing through the cell. In the second system, which uses a torsion balance, the counterbalancing torque is provided by a servo-motor rotating the torsion head. Other types of servo-mechanism are, however, possible.

THE COULOMETER-TYPE DIFFERENTIAL THERMOBALANCE

Preliminary investigations into the design of a suitable differential thermobalance were carried out using a silver coulometer in conjunction with an air-damped analytical balance. The silver coulometer provides an electrochemical means of converting current into its equivalent rate of change of weight because the passage of 1 A through the cell deposits silver on the cathode at the rate of 1·118 mg/s, with corresponding loss from the anode. The arrangement of the experimental apparatus is illustrated diagrammatically in Fig. 1.

The analytical balance was adapted so that the sample under test was suspended from one arm and was counterbalanced by the silver anode hung from the other arm by a fine platinum-wire conductor to minimize surface-tension effects. As the weight of the sample changed, balance was restored by corresponding change in weight of the suspended silver electrode due to a control current passing through the cell. The necessary control was effected by a photocell movement detector and a magnetic amplifier, the current output of which was rectified and passed through a silver

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Thermogravimetric analysis should not be confused with nal analysis; the latter is the method for measuring thermal ges in substances being heated under uniform conditions.

coulometer in such a direction as to restore the system to its balanced position. The voltage drop across a fixed resistance in the control current circuit was applied to a potentiometric recorder to give a continuous record of the differential weight loss. The arrangement of the electrical circuit was similar to that used in the torsion type of balance as shown in Fig. 4.

The apparatus has the merit of giving absolute measurements, though it is subject to the disadvantage that variations in surface-tension forces on the wire cause slight irregularities in operation. This effect may be alleviated by using alcoholic silver nitrate solution as the electrolyte, or by adding to the surface of the electrolyte certain organic liquids which have a low interfacial surface tension with water, or by applying electromagnetic vibrations.

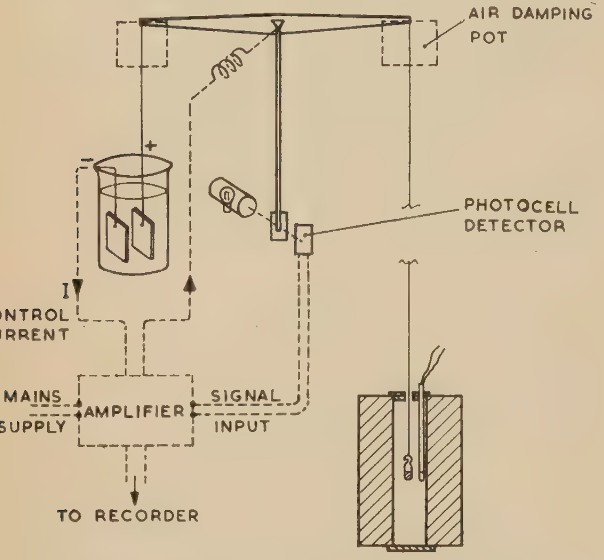


Fig. 1. Diagram of the arrangement of the experimental silver-coulometer type of differential thermobalance

The experimental model proved very satisfactory in operation, and it was only because of lack of facilities that the design of this balance was not pursued to the prototype stage. Instead, a torsion type of balance, described below, was designed and built for routine use because it is more robust, cheaper, and easier to construct than the coulometer type, which would require periodic maintenance such as the replacement of silver electrodes.

THE TORSION TYPE OF DIFFERENTIAL THERMOBALANCE

In the torsion type of balance the counterbalancing torque is automatically applied by means of a small servo-motor geared to rotate the torsion head. The rate of loss in weight is proportional to the rate of rotation of the motor balancing the sample, which is, for this type of motor, proportional to the controlling voltage operating it.

In the description of the balance reference is made to the accompanying drawings: Fig. 2 is a sketch of the balance and furnace assembly, Fig. 3 is a block diagram of the circuit arrangement, and Fig. 4 shows details of the electrical circuit.

Description. A torsion wire is secured to a light aluminium-alloy balance beam by small brass chucks. A fine nichrome wire is attached to a pivot at one end of the beam and carries the specimen in a small container, the container being su pended inside a tubular electric furnace. The torsion wire rigidly supported within a metal framework; one key provided at the rear end for adjusting the tension of t wire and another key for trimming the position of the bea A mask of thin aluminium sheet at the other end of t balance beam moves in front of a selenium photocell a intercepts light from the lamp and optical system. A extension of this mask in the form of a vane passes betwe

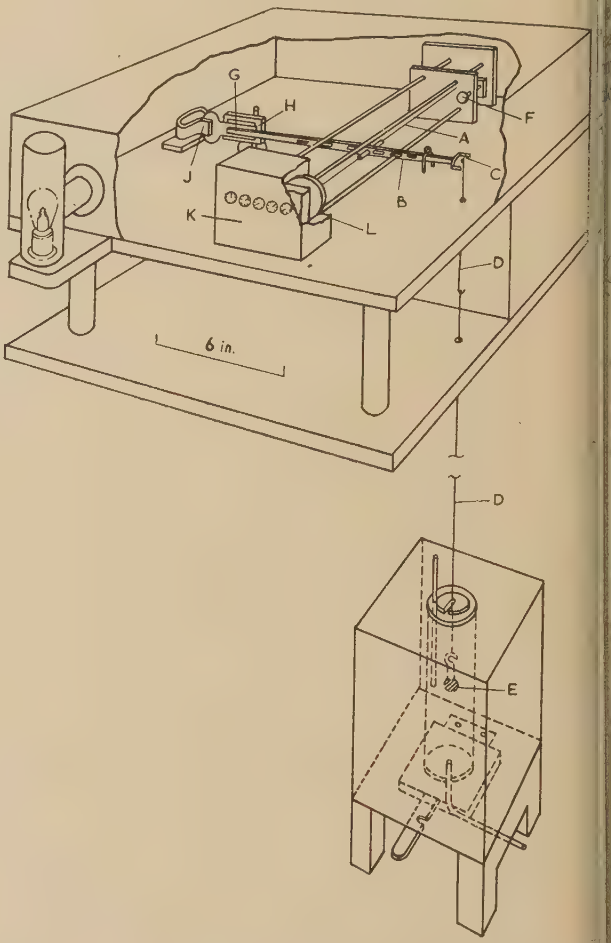


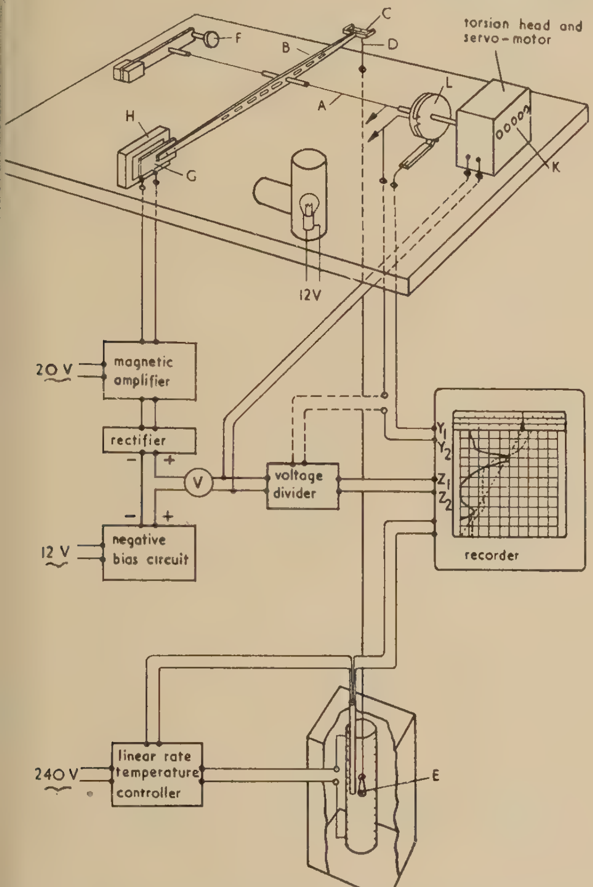
Fig. 2. Sketch of the torsion-type differential balance and furnace assembly

A, torsion wire 15 in. long of stainless-steel violin "E" string; *B*, aluminium-alloy balance beam, overall length 12 in., length from pivot to suspension wire $4\frac{1}{2}$ in., thickness 1/16 in., 5/16 in. wide at pivot tapering to 3/32 in. at ends; *C*, nichrome stirrup wire 37 s.w.g.; *D*, nichrome suspension wire 35 s.w.g.; *E*, sample and container; *F*, tuning-key to adjust tension of wire; *G*, aluminium mask; *H*, photocell; *J*, damping vane and magnet; *K*, torsion-head mechanism; *L*, rotating slide-wire.

the poles of a permanent magnet and serves to damp oscil tion of the balance beam. The servo-mechanism operatin the torsion head consists of a low-inertia integrating mot fitted to the gear train of the dial-counter mechanism of watt-hour meter; the gear reduction ratio is 200 000 : 1. T torsion wire is secured to the appropriate and suitab extended gear spindle of the counter mechanism.

The photocell output is applied to the control windings a single-stage magnetic amplifier, which is connected to stabilized a.c. mains supply. The rectified output from th magnetic amplifier, in series with a negative bias potential, ontrolling electromotive force which operates the servo-r. A proportion of the motor input voltage is recorded measure of the differential weight change. The bias ntial is necessary to give the circuit both negative and ive control. Most of the electrical gear, including the etic amplifier, is contained in a compartment beneath indanyo platform of the balance.

rotating circular slide-wire is provided on an extension e torsion head, the ends being fed by leads from a lardized millivoltage supply. The output taken between side of the supply and the phosphor-bronze brush is a ure of the position of the torsion head, and thus, of the ulative weight loss; this output, compensated as described v, is recorded on the multi-point recording potentiometer.


C
F
B
D
torsion head and servo-motor
A
L
H
G
K
12V
20 V
magnetic amplifier
rectifier
V
voltage divider
Y_1
Y_2
Z_1
Z_2
recorder
negative bias circuit
12 V
240 V
linear rate temperature controller
E

g. 3. Block diagram of the circuit arrangement of the torsion-type differential thermobalance

Y_2, cumulative weight loss, $Z_1 - Z_2$, differential weight loss.

cumulative weight loss is also registered on the dial-ter mechanism of the torsion head.

hen the system is operating, the balance beam is deflected its null position to expose a portion of the photocell rding to the rate of weight loss, and the recorded cumu-e weight loss lags because of the retarded position of the on head. This error, amounting to about 0·5 mg for rate-of-weight-loss interval of 1 mg/min, is auto-cally compensated on the recording by adding the voltage across a small resistance RV_1 in the servomotor control it to the voltage output of the rotating slide-wire, as n in Fig. 4. The servo-motor and recording potentio-r may be together switched by the ganged switch S_1 from the control circuit to a stable low voltage supply. This coupling allows the torsion head to be turned back to zero position and the recorded rate of weight change to be standardized.

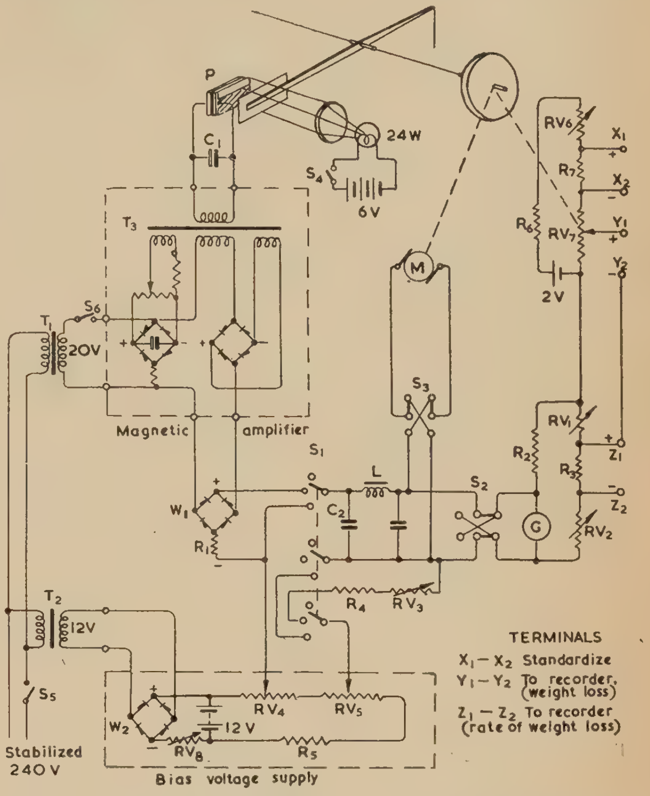

P
C_1
24W
S_4
6V
RV_6
X_1
R_7
X_2
R_6
RV_7
Y_1
Y_2
2V
M
T_3
S_6
T_1
20V
S_3
Magnetic amplifier
S_1
L
C_2
RV_1
R_2
R_3
Z_1
S_2
G
Z_2
RV_2
W_1
R_1
T_2
12V
R_4
RV_3
S_5
Stabilized 240 V
W_2
RV_4
RV_5
12 V
RV_8
R_5
Bias voltage supply
TERMINALS
$X_1 - X_2$ Standardize
$Y_1 - Y_2$ To recorder (weight loss)
$Z_1 - Z_2$ To recorder (rate of weight loss)

Fig. 4. Details of the electrical circuit of the torsion-type differential thermobalance using a magnetic amplifier

$R_1 = 5\ \Omega$
$R_2 = 1\ k\Omega$
$R_3 = 2\ \Omega$
$R_4 = 50\ \Omega$
$R_5 = 50\ \Omega$
$R_6 = 40\ \Omega$
$R_7 = 0{\cdot}3\ \Omega$

$RV_1 = 0{\cdot}1\ \Omega$
$RV_2 = 200\ \Omega$
$RV_3 = 200\ \Omega$
$RV_4 = 10\ \Omega$
$RV_5 = 100\ \Omega$
$RV_6 = 10\ \Omega$
$RV_7 = 1\ \Omega$
$RV_8 = 15\ \Omega$

$C_1, C_2, C_3 = 2000\ \mu F$
$L = 50$ H
G = voltmeter, 0–10 V
M = servo-motor, Electro Methods low-inertia integrating motor, type 901, 6 V
P = selenium photocell
T_1, T_2 = mains transformers
T_3 = magnetic amplifier, Electro Methods type 560
W_1, W_2 = selenium rectifiers, S.T.C. B35–1–2

Alternative electrical circuits. There are, of course, many possible relay circuits for translating beam movement into the electromotive force controlling the motor. The phototransistor circuit, shown in Fig. 5, has proved one attractive and satisfactory alternative to that previously described. It consists basically of a phototransistor and a 6 V accumulator which together directly operate the low-inertia integrating motor. This arrangement is recommended because it is simple and cheap to construct, it obviates the need of an amplifier, and is stable in operation. The phototransistor requires careful mounting, however, for it may be affected by temperature-changes and it has a small light-sensitive area. As with the magnetic-amplifier circuit, a negative bias potential is required, and a proportion of the voltage applied to the motor is recorded. Another alternative circuit, which has proved both simple in design and successful in operation, employs a thyratron valve (type 2D21) and a photoelectric cell (type 90 CV).

Calibration and standardization. Before the apparatus is put into use the dial counters are calibrated to read directly in milligrams, by testing with known weights and adjusting the length of torsion wire between the balance beam and torsion head. Before each test run the recording of rate of weight loss has to be checked by applying a standardizing voltage, say 3·00 V, to both the servo-motor and recorder circuit. The rate of weight loss equivalent to this voltage is ascertained beforehand by timing the rotation of the dial counters: for example, with the present balance 3·00 V gave 1002 dial divisions per minute, which is equivalent to 10·02 mg/min. The proportion of this voltage supplied to the recording potentiometer is finely adjusted by the sensitivity resistance RV_2 (Fig. 4) until the pointer registers at the appropriate point (e.g. 10·02) on the calibrated scale of the recorder. With the present 10 in. width of chart a scale representing a rate of weight loss of 2 mg/min to the inch has been found suitable for most work. Also before each test run the recording of the cumulative weight loss has to be standardized: to do this, the millivoltage supplied to the ends of the circular slide-wire is regulated by resistance RV_6 to a predetermined value so that the loss of weight is recorded in suitable units on the chart scale. A scale representing 50 mg to the inch has been found convenient. The response time of the balance system may be varied by altering the length of torsion wire between the balance beam and tensioning device, the position of the photocell and intensity of illumination, and the electrical amplification.

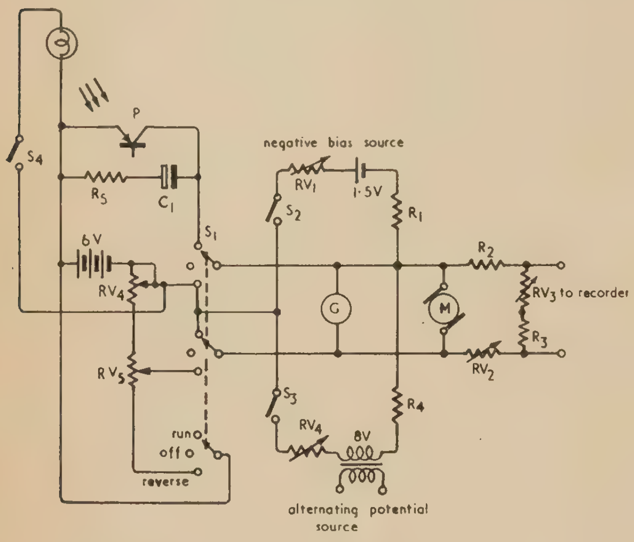


Fig. 5. Alternative phototransistor control circuit

$R_1 = 1\ \mathrm{k}\Omega$
$R_2 = 1\ \mathrm{k}\Omega$
$R_3 = 10\ \Omega$
$R_4 = 2\ \mathrm{k}\Omega$
$R_5 = 3\ \mathrm{k}\Omega$

$RV_1 = 2\ \mathrm{k}\Omega$
$RV_2 = 500\ \Omega$
$RV_3 = 2\ \Omega$
$RV_4 = 2\ \mathrm{k}\Omega$

$C_1 = 3000\ \mu\mathrm{F}$

$G = 0\text{–}10\ \mathrm{V}$

M = servo-motor, Electro Methods low-inertia integrating motor, type 901

P = phototransistor OCP 71

Servo-motor characteristics. The successful operation of the balance must be attributed mainly to the remarkably accurate performance of the low-inertia motor. Tests on the type 901 motor as fitted in the instrument showed that, for practical purposes, the speed of the motor is directly proportional to the applied voltage over the working range up to 7 V. The voltage/speed curve (Fig. 6, curve *B*) deviates appreciably from linearity below 50 mV with the motor stalling about 30 mV input, but over this range the errors are relativ unimportant. It was found that these errors could be reduc to insignificance by superimposing on the motor input alternating small potential using a bell-transformer and seri resistance as shown in the phototransistor circuit, Fig. With this modification to the motor the linearity of t voltage/speed curve (Fig. 6, curve *C*) was extended to 20 m and the stalling voltage was reduced to 15 mV or less. Slig vibration of the armature caused by the alternating curre thus helped to overcome frictional losses and irregular brus contact, which were apparent at low speeds near the stalli point. The actual errors in terms of rate of weight loss a within ±0·03 mg/min over the recorded range of 0

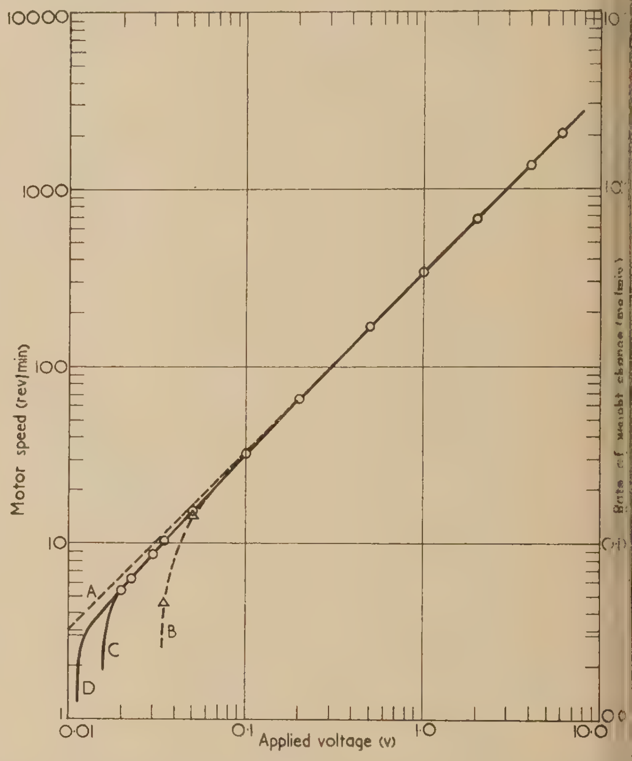


Fig. 6. Linearity tests of low-inertia motor, type 901, as fitted to the torsion head of the differential thermo-balance

Curve *A*, ideally linear characteristic; curve *B*, using high-impedance voltage source but without alternating potential added; curve *C*, using high-impedance voltage source with alternating potential; curve *D*, using low-impedance voltage source with alternating potential.

20 mg/min and, falling within the accuracy of the recordi potentiometer, may be neglected. The backlash betwe gears in the torsion head mechanism was taken up by sprin loading the drive spindle; with this precaution no irregularit in operation were observed. The servo-mechanism operat smoothly and has shown no tendency to hunt.

Performance and range of operation. The torsion balan in its present form and state of adjustment can record tot weight changes of up to 0·5 g at a maximum rate of 30 mg/mi Samples between 0·2 g and 2 g in weight are normally tak with a total suspended load of about 6 g. The cumulati weight change is registered on the dial-counters to the neare 0·1 mg to an accuracy within ±0·5% of the absolute weig o the nearest 1 mg on the recorder chart. The recorded of change of weight can be read to within 0·2 mg/min.

THE ASSEMBLY FOR DIFFERENTIAL THERMOGRAVIMETRIC ANALYSIS

e *linear-rate temperature controller.* In thermo-metric analysis samples are heated at a linear rate of erature-rise, and this heating rate should be maintained onstant as possible because the rate of thermal decom-ion is very susceptible to variations in heating. An matic furnace regulator with a proportionating system ontrol has been specially devised for this purpose. In its gn advantage was taken of the fact that the electromotive e generated by a chromel/alumel thermocouple is prac-ly linear with temperature over wide working ranges.

he scheme of operation may be followed from the circuit ram (Fig. 7). A rotating slide-wire potentiometer pro-s a linearly increasing millivoltage potential which is ied differentially to the output of a chromel/alumel nocouple located in the furnace. The resultant potential-rence is amplified by means of a reflecting galvanometer, ocell, and magnetic amplifier. The rectified output of the lifier is applied to the primary windings of a saturable-reactor, which then regulates the mains current supplied he furnace and thus the temperature of the furnace.

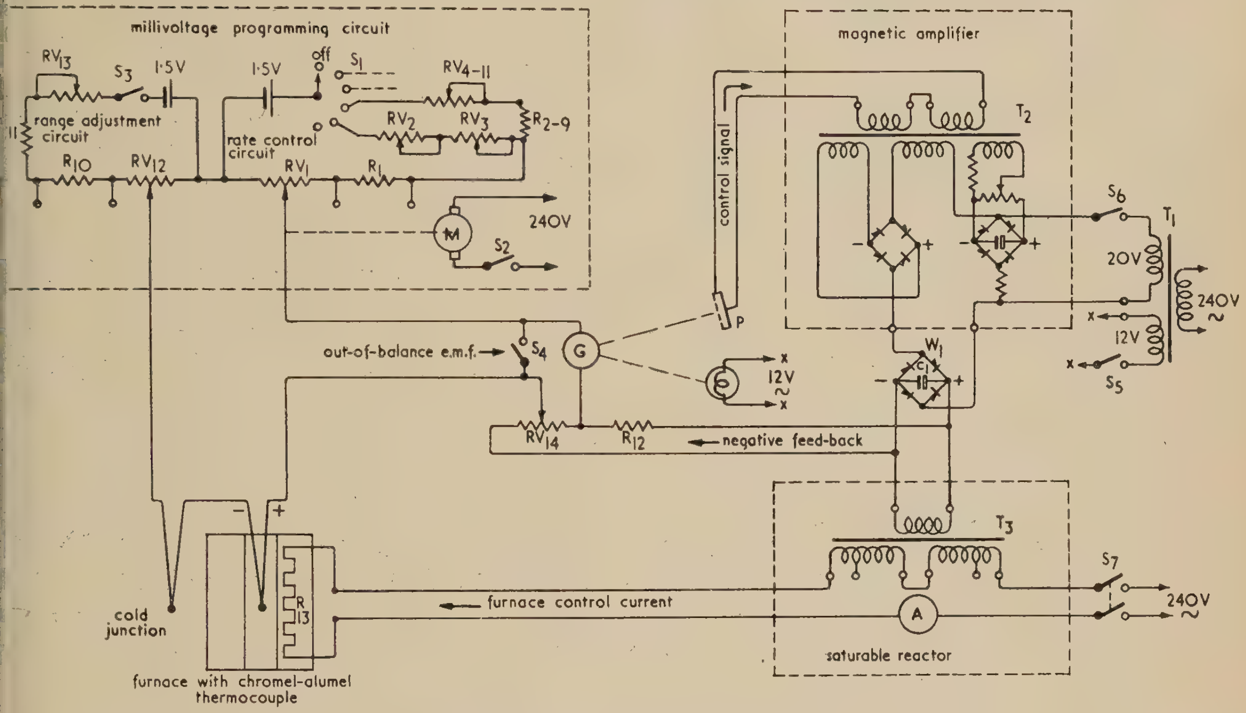


Fig. 7. Circuit diagram of linear-rate temperature controller

$R_1 = 2\ \Omega$
$R_2 = 50\ \Omega$
$R_3 = 15\ \Omega$
$R_4 = 10\ \Omega$
$R_5 = 50\ \Omega$
$R_6 = 100\ \Omega$
$R_7 = 50\ \Omega$
$R_8 = 200\ \Omega$
$R_9 = 300\ \Omega$
$R_{10} = 7{\cdot}5\ \Omega$
$R_{11} = 600\ \Omega$
$R_{12} = 100\ \text{k}\Omega$
$R_{13} = 100\ \Omega$, 600 W, furnace winding

$RV_1 = 5\ \Omega$ slide-wire
$RV_2 = 100\ \Omega$
$RV_3 = 1500\ \Omega$
$RV_4 = 50\ \Omega$
$RV_5 = 50\ \Omega$
$RV_6 = 100\ \Omega$
$RV_7 = 100\ \Omega$
$RV_8 = 200\ \Omega$
$RV_9 = 250\ \Omega$
$RV_{10} = 500\ \Omega$
$RV_{11} = 500\ \Omega$
$RV_{12} = 20\ \Omega$, 10-turn helical
$RV_{13} = 150\ \Omega$
$RV_{14} = 25\ \Omega$

A = 0–5 A
$C_1 = 50\ \mu\text{F}$
G = reflecting galvanometer, taut suspension; sensitivity, 1 mm/µF at 1 m
M = synchronous motor
P = selenium photocell
T_1 = mains transformer for lamp and amplifier
T_2 = magnetic amplifier, type 560 (by Electro-Methods Ltd.)
T_3 = 1-kVA saturable reactor
W_1 = rectifier, type B45-1-1 (by Standard Telephones and Cables Ltd.)

The linearity of response and stability of the amplifier unit are much improved by feeding back a negative signal from the control windings of the saturable reactor to the galvanometer circuit. The ratio of the feedback e.m.f. to the out-of-balance e.m.f. is about 0·9. With this feed-back arrangement the control system is largely independent of circuit characteristics, and errors due to non-linearity of the amplifier are much reduced.

The millivoltage supplied to the ends of the rotating slide-wire potentiometer determines the rate of temperature-rise; a 1·5 V dry cell and a network of resistances with switch S_1 enable the appropriate millivoltage potential and hence the heating rate to be selected at will. An adjustable source of millivoltage provided by a separate 10-turn helical potentiometer is fed into the galvanometer circuit for the purpose of setting the lower limit of the working range of temperature as required. Terminals are provided for standardizing both the rate-control and range-adjustment circuits according to a calibration chart. Other details in the circuit diagram are self-explanatory.

Although for most routine work heating rates of either 3° or 6° C per minute are used, provision has also been made for several rates of heating between 0·5° and 15° C per minute over the temperature range 30° to 900° C and for periods up to 200 minutes without resetting the slide-wire. The heating rate over several hundreds of degrees of operation can be maintained to an accuracy of ±2%. With reduced feed-back and with high sensitivity of the galvanometer the temperature controller can be used as a sensitive thermostat regulating the temperature of the furnace to within ±½° C indefinitely.

The sample container. For studying the pyrolysis of coals and related compounds up to temperatures of 700° C, a Pyrex retort tube in the shape of a miniature flask of 2 to 3 ml capacity has been found satisfactory and convenient as a sample container. After the tube has been charged with a known weight of sample, the upper end is drawn down to a small diameter of about 2 mm and bent into a hook for the purpose of suspension. It is considered that a retort tube of this form helps to maintain standard conditions in the sense that the substance decomposes completely within its own atmosphere of gaseous products and is unaffected by the atmosphere of the furnace.

The experimental conditions are largely a matter of choice depending upon requirements, but an open crucible and a controlled furnace atmosphere have been avoided, unless particularly required, as the composition of the atmosphere and rate of removal of volatiles are factors which may materially affect the course of decomposition. For ignition experiments in air, however, a small flat silica dish as sample container has been found suitable.

Consideration has to be given to buoyancy changes of the sample and its container due to decrease in gas density of the furnace atmosphere with rise in temperature. Experiments were conducted to measure the change in apparent weight of the empty sample containers due to buoyancy and other causes when heated uniformly from room temperature to 600° C. The unsealed Pyrex tube apparently gained 0·23 mg, the sealed Pyrex tube 1·4 mg, and the silica dish 0·55 mg. For most tests these small errors may be neglected, particularly as the density of the gaseous products within the retort produces other minute errors in weight which are difficult to determine. The effect of buoyancy on the rate of change of weight measurements was thus found to be insignificant and was therefore disregarded.

A performance test of the assembly. A performance test was conducted to determine the order of repeatability of the differential pyrolysis curves at various levels of operation of the apparatus. Several samples of different weights from 0·3 to 1·5 g of the same coal were heated under the same carbonizing conditions. The peak values of decomposition rates (expressed as per cent weight loss per °C) and temperature are compared in the table.

Comparison of peak values for different weights of a coal sample

(Heating rate approximately 4·5° C per min)

Sample weight (g)	0·334	0·511	0·675	0·999	1·197	1·504
Maximum rate of weight loss (% per °C)	0·231	0·236	0·229	0·234	0·239	0·237
Peak temperature (°C)	458	458	458	460	458	457

A statistical analysis of this set of results showed that the standard deviation due to all experimental errors was ±0·0036 (or ±1·5%) about the arithmetic mean of 0·234, and that one result in every forty would probably exceed a deviation of ±3% from the mean. There appeared to be no significant bias of the peak values with sample weight or the operating level of the balance. The maximum deviations of the peak temperatures were ±1·5° C.

An example of application. A typical example of a cha record of the cumulative and the differential weight-lo curves for the pyrolysis of coking coal is reproduced in Fig. This and other examples which have been given by the auth elsewhere(4) indicate how useful the technique can be characterizing compounds by their peak decomposition value

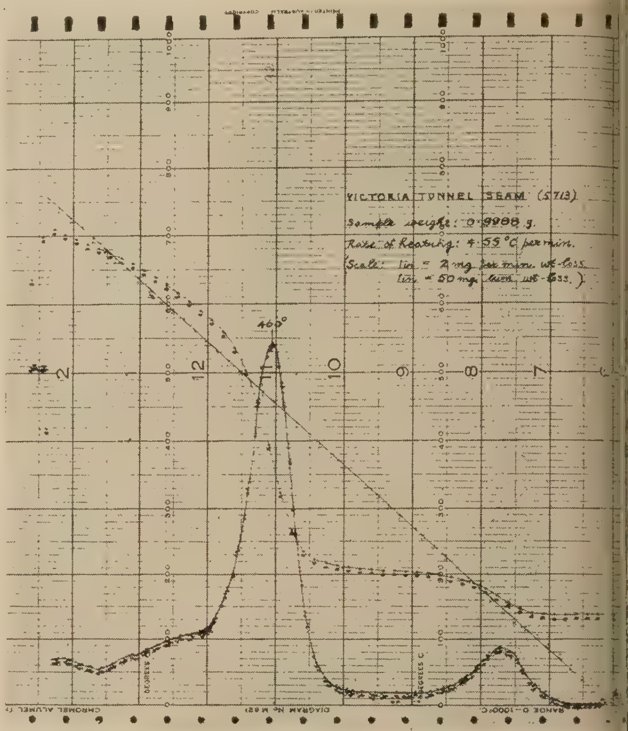


Fig. 8. Typical chart record obtained with the torsion-type differential thermobalance; pyrolysis curves of coking coal

Although originally designed for coal carbonization resear the apparatus may be employed in other fields of work: f example, to study the thermal behaviour of inorganic a organic substances under various conditions; the kinetics decomposition, adsorption and evaporation; and the partic size distribution of slurries and air-borne dusts.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Brit. Pat. Applic. 20061, 25th June, 1957; paten pending in Australia, U.S.A., etc.
(2) De Keyser, W. L. *Bull. Soc. Franc. Ceram.*, **20**, p. (1953); *Nature* [*London*], **172**, p. 364 (1953).
(3) Erdey, L., Paulik, F., and Paulik, J. *Nature* [*Londo* **174**, p. 885 (1954).
(4) Waters, P. L. *Nature* [*London*], **178**, p. 324 (1956).

A linear, unidirectional anemometer of rapid response

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A heated wire dissipating constant power causes temperature changes in the air moving past it which vary approximately inversely as the wind speed. These temperature changes are detected by a thermometric bridge and, by means of a circuit with feedback control, an electrical signal is constructed which is linearly related to the velocity. The resulting anemometer is sensitive only to the normal velocity component and, by combining two such anemometers, changes in sign of this component can be accommodated. Four fine wires (0·0005 in. tungsten or nickel) are used but they can be replaced if damaged without affecting the calibration. The time constant of the instrument is about 0·3 s at a wind speed of 0·5 ms^{-1} and decreases somewhat at higher speeds.

stigations of atmospheric turbulence have been hampered he lack of a rapidly responding anemometer of stable r calibration sensitive to only one velocity component. boratory work on turbulence, the amplitude of the turbu- velocity fluctuations is, in general, small compared with peed of the mean flow, and the ordinary hot wire anemo- r can be taken as linear for such fluctuations, though a sensitivity which varies with the mean speed.

the atmosphere, on the other hand, the turbulent ity fluctuations are relatively much larger and linearity e hot wire anemometer cannot be assumed. It follows a calibration must be applied before any calculations are e on the anemometer indications with the consequence automatic computations are largely precluded. Forms earized hot wire have been devised which depend on the pensation of the curvature of the anemometer calibration on-linearity somewhere else in the circuit but, because e notorious instability of hot-wire calibrations and the ulty in checking linearity in the field, they have never d general acceptance.

e basic principle used here has been mentioned before, by Ower(1) and Dostrovsky and Llewellyn,(2) but there not seem to have been any detailed discussion of the ical processes involved. The present system of lineariza- also appears to be novel.

THEORY OF VELOCITY-SENSING DEVICE

Fig. 1, consider a long heated wire *AB* and the amount eat passing two strips of unit breadth, *PQ* and *RS*, cut infinite parallel planes lying parallel to *AB*; T, ρ and u the temperature, density and velocity component per- licular to *AB* and *PQ* of the air approaching the apparatus $T + \delta T$, $\rho + \delta\rho$, $u + \delta u$ those of the air as it leaves. co-ordinate in the direction *PQ* is labelled z and it is med that T, ρ and u (but not δT, $\delta\rho$ and δu) are indepen- of z over a distance comparable with the dimensions of pparatus.

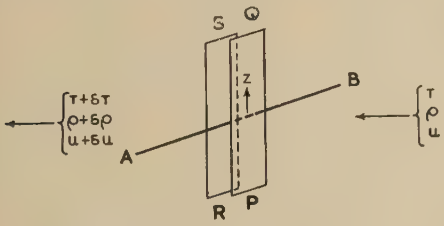

Fig. 1. Principle of anemometer

Provided that *PQ* and *RS* are long enough, the net outflow over the planes *SQ* and *RP* can be taken as zero and the amount of heat crossing the strip *RS* in unit time is equal to that crossing *PQ* together with the amount H convected from unit length of *AB*. (The radiative losses from *AB* can be shown to be small in practice so that H is nearly enough equal to the total amount of heat dissipated per unit length.) That is:

$$c_p\int_{-\infty}^{\infty}[\rho u + \delta(\rho u)](T + \delta T)dz = c_p\int_{-\infty}^{\infty}\rho uTdz + H \tag{1}$$

whence

$$H = c_p\left[\rho u\int_{-\infty}^{\infty}\delta Tdz + \int_{-\infty}^{\infty}\delta(\rho u)\delta Tdz\right]$$

since continuity demands that $\int_{-\infty}^{\infty}\delta(\rho u)dz$ be zero. It follows that

$$H = c_p\left[\rho u\int_{-\infty}^{\infty}\delta Tdz + u\int_{-\infty}^{\infty}\delta\rho\delta Tdz + \rho\int_{-\infty}^{\infty}\delta u\delta Tdz\right] \tag{2}$$

We neglect the third term in comparison with the first. Published data on the velocity field behind a cold wire provides no basis for judging whether or not this is justified because the velocity field in the wake of a hot wire will not necessarily be the same. It is clear that the expansion of the air will tend to annul the velocity defect owing to the presence of the wire. However, even if this third term cannot be neglected, it is likely that δu is proportional to u, in which case the following results are changed only by a constant factor. Neglecting pressure variations we write from equation (2)

$$H = c_p\rho u\left[\int_{-\infty}^{\infty}\delta Tdz - \frac{1}{T}\int_{-\infty}^{\infty}\delta T^2dz\right] \tag{3}$$

or, implicitly defining a new parameter, a,

$$H = c_p\rho u\left[\int_{-\infty}^{\infty}\delta Tdz - \frac{1}{aT}\left(\int_{-\infty}^{\infty}\delta Tdz\right)^2\right] \tag{4}$$

where a is a length which characterizes the width of the temperature wake and which can be given explicit form by expressing the profile of δT as, for example, an error function of z. The infinite limits of integration in equations (1)–(4) require that account be taken of the wake over the whole of its width. It is found in practice that an apparatus of moderate size is adequate.

Equation (4) can be put into the form

$$1/\theta = (1/\Phi) - \alpha \tag{5}$$

where $\theta = \int_{\infty}^{\infty} \delta T dz$, $\Phi = H/(c_p \rho u)$, $\alpha = 1/(aT)$ and $\alpha\theta \ll 1$.

It follows that, if H is sufficiently reduced, it is possible to approach as closely as desired to the relation $\theta = \Phi$ for values of u greater than a chosen minimum. The expression used by Ower corresponds to this approximation. Such a great reduction in H is not desirable in the field, however, lest the temperature differences comprising θ be masked by other, accidental variations.

The value of θ can be measured by placing in the planes PQ, RS two wires having a large temperature coefficient of resistance (λ) and connecting them as opposite arms of a Wheatstone bridge. If δr is the difference in resistance between the two arms caused by θ, then $\theta = l\delta r/r\lambda$ where l and r are the length and initial resistance of the downstream wire.

Fig. 2 shows a graph of $1/\theta$ against ρu for two different values of H where the relationship is seen to be of the form predicted by equation (5). The fact that θ is related with ρu rather than with u alone is of advantage in meteorological applications.

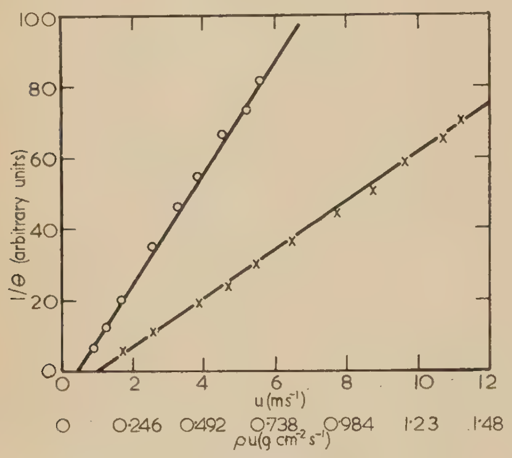

Fig. 2. Relationship between $1/\theta$ and ρu
○, $H = 1{\cdot}83$ W cm^{-1}; ×, $H = 4{\cdot}12$ W cm^{-1}

THEORY OF ASSOCIATED CIRCUIT

The circuit designed to provide a signal inversely proportional to θ and therefore to give a linear measure of ρu is illustrated in block form in Fig. 3.

A source of e.m.f. E_0 is applied through a cut-off device to the Wheatstone bridge. The output e of the bridge is amplified by a factor μ, biased and applied to the cut-off device, the functions of which are, in practice, exercised by the output valve feeding the bridge. The cut-off action is such that E_0 is reduced by a fraction of itself proportional to the (always negative) control voltage $V - \mu e$ which is applied. Then, omitting a possible constant of proportionality

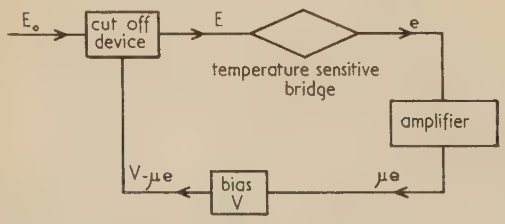

Fig. 3. Block diagram of anemometer circuit

$$E = E_0[1 + \beta(V - \mu e)] \tag{6}$$

If the bridge is not perfectly balanced when $\theta = 0$ but there is an adjustable amount of "initial unbalance," then

$$e = E(\delta r_1 + \delta r_2)/4r$$

for an equal-arm bridge where δr_1 and δr_2 are the contributions to the out-of-balance resistance due respectively to θ and the initial unbalance. Then

$$e = \frac{E}{4r}\left(\frac{\lambda r\theta}{1} + \delta r_2\right)$$
$$= E(k_1\theta + k_2\delta r_2)$$

Hence, using equation (6)

$$E[1 + \beta\mu E_0(k_1\theta + k_2\delta r_2)] = E_0(1 + \beta V)$$

and if δr_2 is adjusted so that $\beta\mu E_0 k_2 \delta r_2 = -1$, then

$$E = \text{const.}\,(1/\theta) \tag{7}$$

The signal E, being inversely proportional to θ, thus becomes the desired linear measure of ρu.

The purpose of using a bias voltage V is to provide an adjustment for the constant in equation (7). In putting $\beta\mu E_0 k_2\delta r_2 = -1$, the minus sign indicates that δr_2 represents unbalance of the Wheatstone bridge in a sense opposite to that caused by δr_1.

The provision of the adjustable δr_2 is not usual in this type of work and it would have been more orthodox to omit it and make μ so large that the term containing θ dominates the coefficient of E. This has not been done here because k_1 and β are quite small (for example, $k_1\theta$ is of the order 10^{-4} for moderate wind speeds). Even if a sufficiently high value of μ could be achieved and maintained in the field there would always be a danger of slightly straining one of the sensing wires. Some sort of field test and adjustment to ensure that δr_2 really was zero would therefore have been needed and orthodoxy would have given no advantage in simplicity of design.

Putting the anemometer into use requires two adjustments: first, one for sensitivity involving the setting of V and, second, the linearity adjustment of δr_2 to its desired value. To make the latter setting, means are provided for transferring some resistance from one fixed arm of the Wheatstone bridge to the other. Two wind speeds are simulated by two resistors which can be switched, in turn, to shunt the appropriate fixed arm. These are so chosen that the decrements of resistance they cause are in the ratio 2 : 1 and the linearity adjustment is set so that the values of E are in the inverse ratio. There is some reaction of the linearity adjustment on sensitivity but, in practice, it is quite easy to achieve the desired settings by successive approximation.

DETAILS OF DESIGN

This anemometer was developed because of the need to measure the vertical component of wind in the lowest layers of the atmosphere, which may be positive or negative. Unfortunately it is not possible to have a horizontal heating wire and a pair of horizontal sensing wires, because when the vertical velocity component passes through zero, the wake n the heater affects both sensing wires and the bridge ses through balance. When this happens, the bridge out- e is zero, there is no cut-off action and E becomes very ge. In this range E ceases to be a linear measure of ρu l it becomes impossible to distinguish between very large l very small velocity components. The type of calibration ich is to be expected from this arrangement and which has n verified experimentally is shown in Fig. 4.

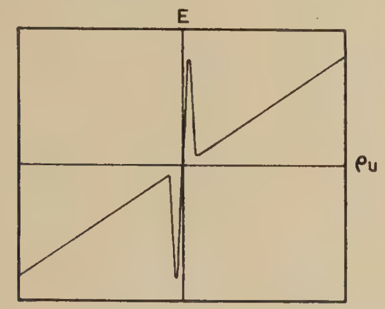

Fig. 4. Undesired type of calibration curve

Except in times of almost complete calm, previous work s shown that the angle of inclination between the wind ocity and the horizontal rarely exceeds 30° within a few ns of metres from the ground, and it was therefore decided construct a pair of anemometers tilted from the horizontal that one responds to $C_1\rho u + C_2\rho w$ and the other to $\rho u - C_2\rho w$, C_1 and C_2 being constants determined by the ometry of the apparatus and u and w now being respectively downwind and vertical velocity components.

The heater and sensing wires should be as thin as possible order to reduce their thermal inertia. The sensing wires re originally of 0·0005 in. annealed nickel which is easy handle and solder but which stretches slowly owing to wind stress on it. They are now of 0·0005 in. tungsten ich is much stronger. The ends of the tungsten wire are pper-plated so that they can be soft-soldered to their pports. The heater is of 42 s.w.g. Nichrome, chosen cause of its low temperature coefficient of resistance, so at the heat dissipated by a given current flowing in it does t vary greatly with wind speed. One strand cannot be ade to give a useful amount of heat so that each heater nsists of seven strands in series arranged by threading one ng piece of wire back and forth through holes in specially ade insulators.

It can be seen from equation (5) that the wake width rameter a should remain constant in all circumstances. While it has not been possible to achieve this exactly, variations have been minimized by the design shown in Fig. 5. Each set of sensing wires must be mounted close to the heater so that variations with wind speed in wake width at the sensing wire remain small compared with the width itself and the line of heater strands shown in section must be parallel to the sensing wire to reduce variations in the wake width intercepted by the latter as the angle of inclination of the wind varies. A multi-strand arrangement is much to be preferred, therefore, to a single heater wire. The two heaters are connected in series so that their currents are equal.

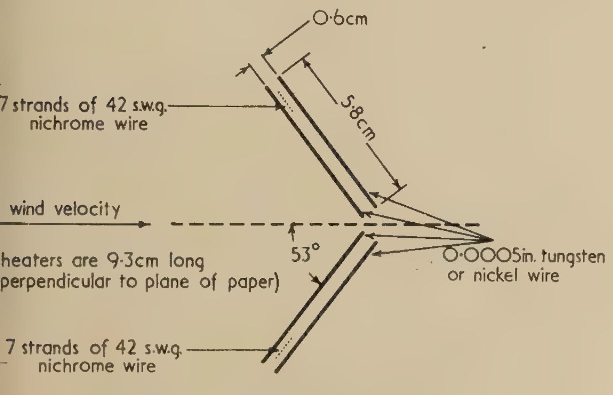
0·6cm
7 strands of 42 s.w.g. nichrome wire
5·8cm
wind velocity
heaters are 9·3cm long perpendicular to plane of paper)
53°
0·0005in. tungsten or nickel wire
7 strands of 42 s.w.g. nichrome wire

Fig. 5. Design of sensing head

A semi-angle of 53° between the two anemometers has been found suitable and, if θ_1 and θ_2 are the values of θ for the upper and lower anemometers respectively, it follows that

$$\frac{1}{\theta_1} - \frac{1}{\theta_2} = 2\frac{c_p}{H}\cos 53^\circ \rho w$$

since values of α for the two anemometers may reasonably be supposed equal. The considerable length (9·3 cm) of heater wire is provided so that large shifts of wind azimuth may be tolerated without mounting the instrument on a vane. The range 0·4 to 0·6 A has been found suitable for heating current and is obtained from the mains by means of a Variac variable auto-transformer. The corresponding range of H is 1·87 to 4·20 W cm^{-1}. Examination of the wake under Schlieren lighting showed no effects of buoyancy due to these rates of heating at speeds above about 30 cm s^{-1}.

The detailed electronic circuit for one of the two anemometers is shown in Fig. 6. Those parts between the lines AA and BB are common to both anemometers and the circuit shown on the right of BB is to be considered as repeated to the left of AA.

The oscillator (V_1 and associated elements) generates a 1200 c/s signal which is then passed to V_2, the latter acting as output valve and the "cut-off device" of Fig. 3. The transformers T_1 and T_2 (with their counterparts for the other anemometer) are mounted on a transformer chassis close to the anemometer mast and are connected by long leads to the rest of the circuit. This makes it necessary to take the h.t. supply out to the transformer chassis but permits the resistances of leads connected to the low-impedance windings of T_1 and T_2 to be kept low. The anemometer output is amplified in V_5, V_6 and V_7, biased by the voltage-dividing network R_{28}, R_{29} and rectified so that a negative d.c. voltage is applied, by way of the smoothing network R_{16}, C_7, C_8, to the grid of V_2 so providing the cut-off action. The filter L_2, C_{29} helps to rid the amplified signal of any noise and stray 50 c/s e.m.f. picked up in leads and chassis.

The signal at the plate of V_2 is proportional to E, the bridge input, and is amplified by V_4 and applied to a differential voltmeter comprising V_9, V_3 and another diode corresponding to V_9. Zero setting is made by means of R_{10}. The output is ±100 μA d.c. through 0·5 MΩ and is at a variable d.c. level above earth. It would not be difficult, however, to provide for other forms of output if desired.

When setting up the anemometer, the bridge is first roughly balanced by means of R_{21} with S_1 open; S_1 is then switched in turn to the two shunt resistors R_{17}, R_{18} while adjustment for linearity is made by setting the initial unbalance on R_{21} as described above. Sensitivity is controlled by adjusting the bias V with R_{29} or the gain of V_4 with R_{22}. In general it is found best to have V set to as small a value as possible.

Perfect balance of the bridge represents a maximum in E and movement of R_{21} in either direction from this position will reduce the meter reading. Thus there is an ambiguity in the setting of R_{21}, the desired 2 : 1 ratio of deflexions for

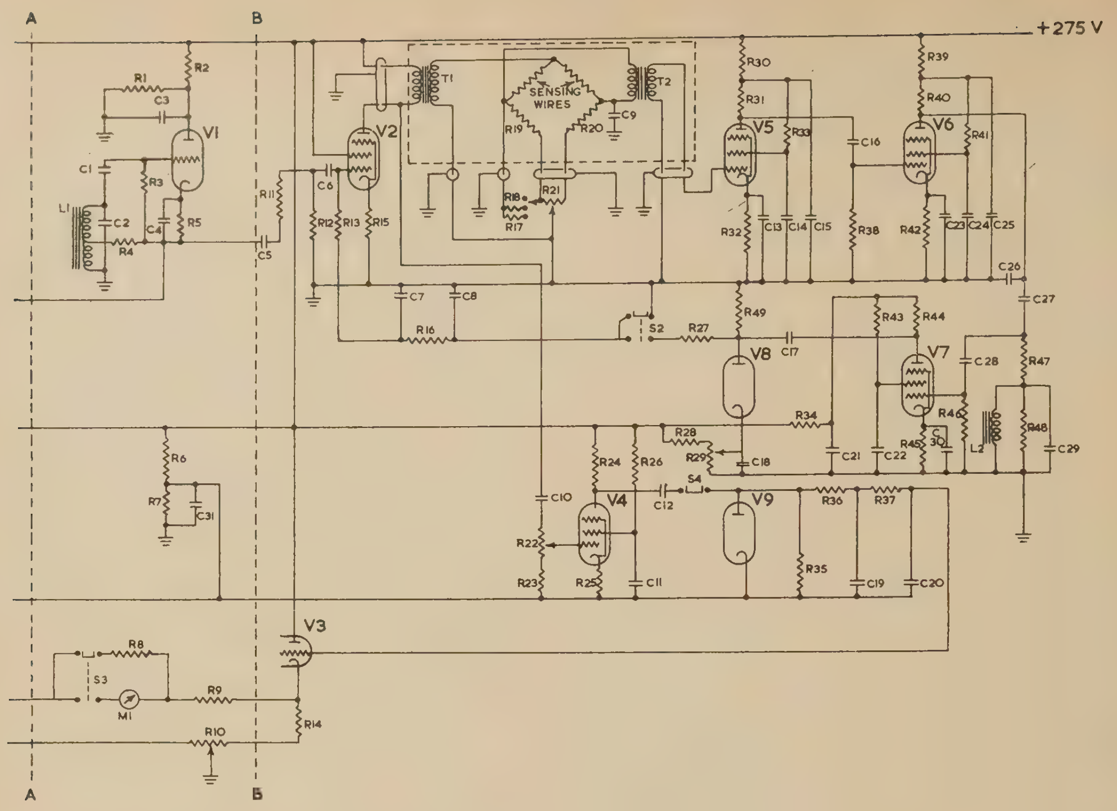

Fig. 6. Circuit diagram of anemometer

R_1 = 47 kΩ
R_2 = 500 kΩ
R_3 = 250 kΩ
R_4 = 39 kΩ
R_5 = 1 kΩ
R_6 = 110 kΩ
R_7 = 34 kΩ
R_8 = 1·3 kΩ
R_9 = 500 kΩ
R_{10} = 10 kΩ
R_{11} = 1 M
R_{12} = 5 kΩ
R_{13} = 250 kΩ
R_{14} = 10 kΩ
R_{15} = 200 Ω
R_{16} = 250 kΩ
R_{17}, R_{18} = (*b*)
R_{19}, R_{20} = 30 Ω

R_{21} (*c*) = 10 Ω
R_{22}, R_{23} = 250 kΩ
R_{24} = 220 kΩ
R_{25} = 1 kΩ
R_{26} = 500 kΩ
R_{27} = 250 kΩ
R_{28} = 1 MΩ
R_{29} = 50 kΩ
R_{30} = 56 kΩ
R_{31} = 100 kΩ
R_{32} = 2 kΩ
R_{33} = 1 MΩ
R_{34} = 56 kΩ
R_{35} = 10 MΩ
R_{36} = 1 MΩ
R_{37}, R_{38} = 1 MΩ
R_{39} = 56 kΩ
R_{40} = 100 kΩ

R_{41} = 1 M
R_{42} = 2 kΩ
R_{43} = 1 MΩ
R_{44} = 100 kΩ
R_{45} = 2 kΩ
R_{46} = 1 MΩ
R_{47}, R_{48} = 22 kΩ
R_{49} = 250 kΩ

C_1, C_2 = 0·001 μF
C_3 = 4 μF
C_4 = 0·1
C_5, C_6 = 0·001 μF
C_7, C_8 = 0·1 μF
C_9 (*a*)
C_{10} = 0·001 μF
C_{11} = 0·1 μF

C_{12} = 0·02 μF
C_{13} = 50 μF
C_{14} = 0·01 μF
C_{15} = 4 μF
C_{16} = 0·001 μF
C_{17} = 0·02 μF
C_{18} = 0·1 μF
C_{19}, C_{20} = 0·01 μF
C_{21} = 4 μF
C_{22} = 0·1 μF
C_{23} = 50 μF
C_{24} = 0·1 μF
C_{25} = 4 μF
C_{26}, C_{27} = 0·0005 μF
C_{28} = 0·001 μF
C_{29} = 0·01 μF
C_{30} = 50 μF
C_{31} = 24 μF

V_1 = 6J5GT
V_2 = EF42
V_3 = 6SN7GT
V_4–V_7 = EF42
V_8, V_9 = EA50

T_1, T_2 = filament transformers 230/6·3V

L_1 = "Wharfdale" Transformer GP8
L_2 = 12H

S_1 = SP 3-T
S_2, S_3 = SP DT
S_4 = SP ST

M_1 = ± 100 μA nominally 1 kΩ

(*a*) Adjusted for best reactive balance. (*b*) Adjusted to give linearity over the desired wind speed range. (*c*) Specially made helical potentiometer.

the two test shunts can be obtained in two ways. The sense in which R_{21} is connected is important, therefore, and care must be taken to move it in the correct direction from the balance point.

Microphoning in T_2 and V_5 was occasionally found to be troublesome but was eliminated by mounting these components on rubber. The switch S_2 opens the feedback loop and is very useful in the location of faults.

PRACTICAL PERFORMANCE

The anemometer has been calibrated in a wind tunnel at various angles of inclination and azimuth. Test resistors (R_{17} and R_{18} of Fig. 6) of 10 and 5 kΩ or 3·34 and 1·70 kΩ have been used with test settings 50 to 100 μA or 30 to 60 μA, heater currents 0·4 or 0·6 A and nickel or tungsten sensing wires. Various combinations of these factors gave mutually consistent calibrations, of which two are shown in Figs. 7 and 8.

The accuracy is clearly high enough for all measurements connected with atmospheric turbulence although some scatter is evident, particularly when the sensitivity is greatest. Breakage and replacement of a sensing wire have been show experimentally not to affect the calibration, provided, course, that the linearity and sensitivity adjustments are mad anew after the repair.

The response time is not a simple constant since it combin characteristics of the electronics and of the aerodynam properties of the sensing head. The electronic time consta is fairly easily measured and is about 0·12 s. The tin constant of the sensing head depends on the wind speed ar on whether it refers to a change of wind speed (involving t thermal inertia of the heater wires) or a change of angle the horizontal (involving the very much smaller therm inertia of the sensing wires). Calculations assuming a 30 velocity fluctuation show that the time constant of the sensi head varies between 0·21 and 0·07 s over the speed ran 0·5 to 10 m s^{-1}. This may be added to the electronic respon time and an overall time constant of 0·3 s at worst is indicate

SOME ASPECTS OF FIELD USE

Before wind-tunnel calibrations can be confidently appli in the field, some account must be taken of the possib

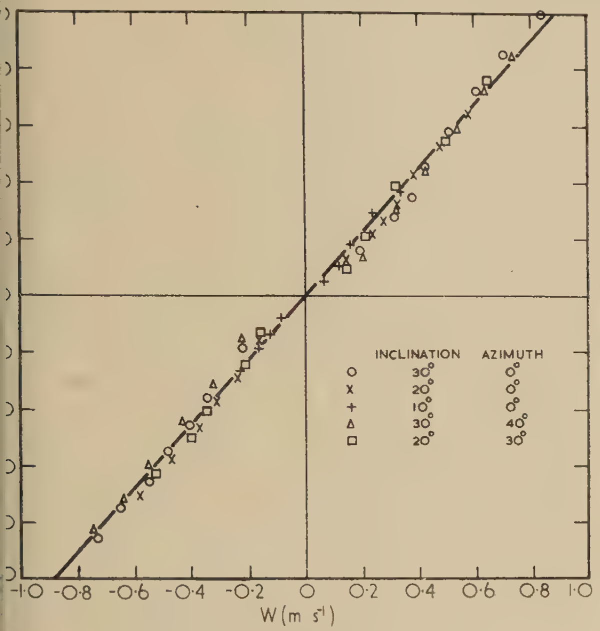

Fig. 7. Anemometer calibration

st resistors, 3·34 and 1·70 kΩ; test settings, 100 and 50μA; eater current 0·4 A; sensing wires 0·0005 in. tungsten.

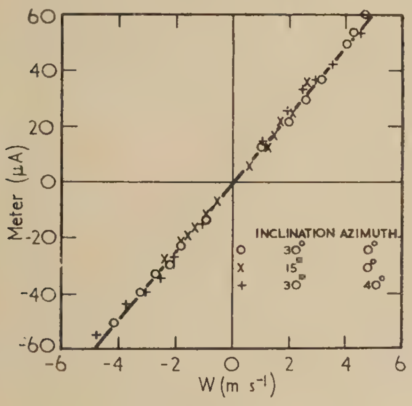

Fig. 8. Anemometer calibration

st resistors, 10 and 5 kΩ; test settings, 100 and 50 μA; heater current, 0·6 A; sensing wires 0·0005 in. nickel.

s of differential solar heating on the sensing wires and turally occurring temperature gradients in the atmo- e. For purposes of comparison we need an estimate e temperature differences between the sensing wires h can arise as a result of the action of the heater. Here accurate enough to put $\theta = H/c_p\rho u$ and, typically, u t be 1 m s⁻¹ with a value for H of 1·87 W cm⁻¹ or 10 m s⁻¹ with H 4·20 W cm⁻¹. The corresponding values of θ are 28·0 and 6·3° F cm. As the sensing wires are 5·8 cm long, the differences in mean temperature are 4·8 and 1·1° F.

To estimate the effect of direct insolation we assume the (extremely high) flux of radiation 0·1 W cm⁻² incident normally on wire having an absorption coefficient of 40%. The wire temperature will then be raised above that of the air by 0·07 and 0·15° F in wind of 10 and 1 m s⁻¹ respectively. Differential effects will be much smaller provided that both wires receive equal amounts of radiation but, because of the danger of one part of the instrument casting a shadow on another part, it would appear wise to use a rough shield to shade the whole apparatus.

When a naturally occurring temperature gradient imposes a value of θ in addition to that caused by the heater we may write

$$E = \text{const.}\ \frac{1}{\theta_1 + \theta_2}$$

$$= \text{const.}\ \frac{1}{\delta T_1 + \delta T_2}$$

where θ_1 and δT_1 are the values of θ and mean temperature difference due to the heater and θ_2 and δT_2 those due to the temperature gradient. It follows that E is reduced from its correct value by a factor $[(1 + \delta T_2)/\delta T_1]$ where, as shown above, 4·8 and 1·1° F may be typical values of δT_1.

In order to seek information on the magnitudes of temperature gradients occurring in the atmosphere, a temperature sensitive bridge, similar to one of the anemometers, was constructed. It was driven from a constant source of 1200 c/s alternating current and the output was recorded, after amplification, by an oscilloscope and camera. A standardizing signal was obtained by switching a known resistance in parallel with one arm of the bridge.

The records showed rapid and frequent temperature differences of the order 0·02° F, which will cause errors in anemometer indication of 2% at the worst. Superimposed on them, however, were less frequent "spikes" showing much larger temperature differences of duration less than about 0·05 s. The table shows the average number of such temperature differences observed in five-minute periods at two heights above the ground. The observations were all made at wind speeds between 1·3 and 3·3 m s⁻¹ and with net incoming radiation between 24 and 70 mW cm⁻¹.

It will be seen that the relative infrequency and the very short duration of these large temperature differences makes them unimportant for all practical purposes, particularly since the time constant of the anemometer is such as to prevent it from responding at all completely to such transient effects.

ACKNOWLEDGEMENTS

The design owes much to discussions with many people, particularly Mr. E. L. Deacon, Dr. A. A. Townsend and Dr. A. J. Dyer, the last of whom has also carried out measure-

Frequency of temperature differences over 0·6 cm in the lower atmosphere

Height (in)	*Number of occasions in 5 min. when temperature differences lay between limits (°F)*							
	< 0·2	0·2/0·4	0·4/0·6	0·6/0·8	0·8/1·0	1·0/1·2	1·2/1·4	> 1·4
0·5 (mean of 7 obs.)	30	52	30	13	7	4	3	1
2 (mean of 9 obs.)	34	22	6	1	1	0	0	0

ments and calculations bearing directly on the validity of equation (4). Much of the detailed electronic design is due to Mr. R. R. McGregor. Mr. G. H. Harris constructed the sensing head and the special potentiometers used in adjusting the bridge balance.

REFERENCES

(1) Ower, E. *Measurement of Air Flow*, 3rd Ed. (Londo Chapman and Hall Ltd., 1949).
(2) Dostrovsky, J., and Llewellyn, D. R. *J. Sci. Instru* **25**, p. 137 (1948).

A magnetic gauge utilizing the magnetron effect

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The cut-off region of a magnetron diode is shown to be an accurate, though relative measure of the magnetic field. This magnetron effect is utilized to calibrate a sub-miniature diode to serve as fluxmeter. Only simple ancillary apparatus is required and accuracies greater than 1% are easily attainable. Conditions which such a fluxmeter has to fulfil for satisfactory operation are stated, and experiments prove these to be met.

The effect of inserting symmetrically a planar or cylindrical diode in a uniform magnetic field is well known. Theory predicts a critical relationship between the accelerating electric field owing to the applied anode potential and the uniform magnetic field which is perpendicular to it. In the case of the cylindrical diode this is given by

$$(e/m)B_c^2[1 - (r_c/r_a)^2]^2 = 8(V_a + V_p)/r_a^2 \qquad (1)$$

where V_a is the applied anode potential relative to cathode, V_p the contact potential, B_c the magnetic cut-off field, r_c and r_a, the cathode and anode radius respectively and e/m the specific electronic charge.

For anode potentials V_a less than, or magnetic fields B greater than that given by equation (1), electrons, which have been emitted from the cathode with zero initial velocity, should just fail to reach the anode.

The observed cut-off is, however, not as sharp as equation (1) would suggest. There is quite a tail formation and anode currents are recorded much in excess of the critical condition given by equation (1). Considerations of initial velocities grossly fail to account for it and this phenomenon, which could be termed as the magnetron effect, has been the subject of much investigation.(1–4) It might perhaps be added that the cut-off condition given by equation (1) holds for all electric field configurations for the given regular geometry assumed (cylindrical or planar), so long as it is everywhere perpendicular to the uniform magnetic field B, i.e. is a function of one co-ordinate only, is continuous and free from singularities. Space charge would not violate it so long as its effect would be restricted to that of a continuous electric fluid of volume density ρ. On the other hand, equation (1) does not take account of detailed electron-electron scattering, the result of which would certainly be to upset the simple cut-off condition expressed by it. Similarly, edge effects are also not included.

Since such scattering processes can never be entirely absent, one can therefore expect space charge conditions to affect the cut-off. This is so, though not in a manner that a cursory examination of the problem might suggest. Recent investigations(5) have shown that, perhaps surprisingly so, the cut-off becomes considerably less sharp as the anode current I_{a0}, which, at fixed V_a flows at $B = 0$, is reduced (I_{a0} can be altered by varying the cathode temperature). Under extre temperature-limited conditions, with I_{a0} only a few mic amperes, the cut-off is extremely sluggish, considera anode current still flowing well in excess of the limiting co ditions of equation (1). Increasing I_{a0}, the cut-off becom progressively sharper until, well in the space charge regio it is virtually independent of I_{a0}. This condition was fou to hold for all manner of diodes.

This magnetron effect, however, is strongly dependent up V_a and, in fact, the position of the cut-off knee has in co junction with equation (1), or rather its equivalent for plana geometry, been successfully employed in the measurement small, inaccessible, inter-electrode clearances; this notwi standing the difficulties encountered in adequately accounti theoretically for the magnetron effect. These points will discussed in future publications. Fig. 1 indicates sch matically the experimental results discussed above.

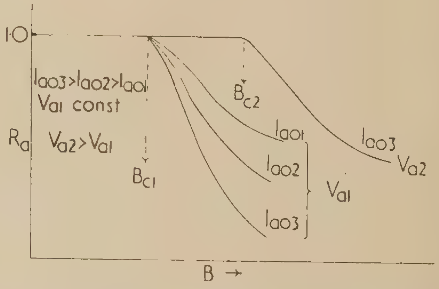

Fig. 1. R_a shown schematically as a function of B with I_{a0} and V_a as parameters

I_{a0} = anode current for $B = 0$.
I_{aB} = anode current with B switched on.
$R_a = I_{aB}/I_{a0}$.
$B_{c1}/B_{c2} = (V_{a1} + V_p)^{\frac{1}{2}}/(V_{a2} + V_p)^{\frac{1}{2}}$.

Though the magnetron effect has as yet defied adequ theoretical treatment, it has, as observed by the author, outstandingly useful property. This is its remarka repeatability which was successfully employed in the measu ment of magnetic fields. Defining

$$R_a = I_{aB}/I_{a0}$$

(where I_{aB} is the anode current flow with magnetic field and I_{a0} the anode current for $B = 0$, with V_a fixed and symmetrically inserted in *B*) its value was found, g to its repeatability and ease of measurement, to be curate measure of the magnetic field. Use of space e conditions, i.e. a region where R_a varies little with I_{a0}, ated measurements by obviating the need to monitor I_{a0} ately, which, of course, is difficult in view of its rapid ion with cathode temperature.

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DESCRIPTION OF SUB-MINIATURE DIODE

enable magnetic fields to be measured in confined spaces, as narrow gaps between pole pieces, the overall size of alve should be as small as possible; and to approach a measurement of *B* as closely as possible the same con- n in turn holds for the dimensions of the electrodes, it is an average value of *B* that is measured over the ne of the inter-electrode spacing.

e valve employed in the measurements is the com- ally-available sub-miniature diode type EA 76. Bulb nsions and a cross-section of the electrodes are shown g. 2. It has an indirectly heated cathode and the relevant inal characteristics are: cathode coating length, 7·5 mm; me enclosed by anode approximately 13 mm^3; nominal r voltage, 6·3 V; nominal heater current, 0·15 A er leads independent of cathode); maximum anode nt, 9 mA.

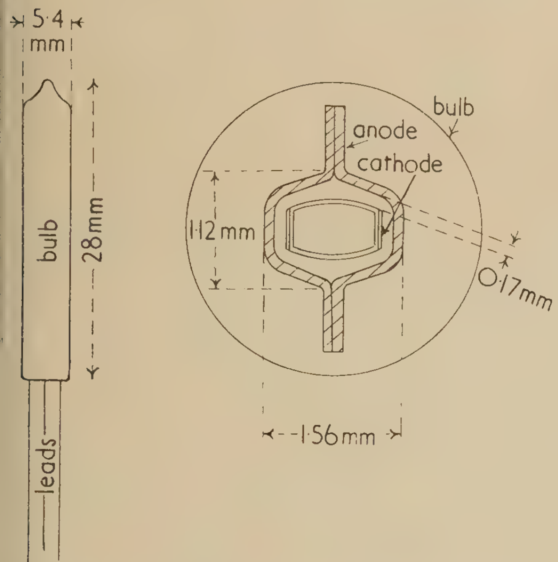

Fig. 2. Constructional details of valve, type EA76

e anode and cathode are both made of nickel; but eas the operating temperature of the latter is above the e point, this is not the case with the anode. Its ferro- etic properties might therefore be expected to interfere the measurements. An inspection of the anode structure indicate that any induced demagnetizing field within the e and due to it cannot be very serious. In any case, the accurate repeatability of the R_a measurements in them- s justify the method, precluding at the same time any urable interference due to hysteresis.

ough the valve is very small, a knowledge of the resources abilities of the valve industry indicates that this might et represent the lowest limit in size of indirectly heated es. Apart from the cross-sectional area of the anode, a shortening of its effective length (7·5 mm) should not offer too much difficulty. One must add, of course, that this valve, which is commercially available, has not originally been designed to be put to such use, although it proved very satisfactory.

INITIAL TESTS AND CALIBRATION OF DIODE

Other variables apart, the value of R_a is strongly dependent upon the symmetry of the valve position with respect to the magnetic field. Means were available of adjusting and measuring the angular co-ordinates θ_1 and θ_2 of the valve with respect to *B*, the θ_1 axis being perpendicular to *B* and the θ_2 axis perpendicular to the θ_1 axis and the axis of the valve. Both θ_1 and θ_2 could be measured to within $\pm\frac{1}{2}^\circ$. The valve could also be rotated about its own axis (θ_3), but R_a proved independent of it and measurements of θ_3 were therefore not considered necessary. Fig. 3 indicates the disposition of the axes of rotation.

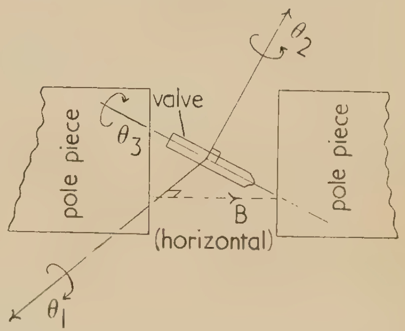

Fig. 3. Disposition of axes of rotation

θ_1, axis perpendicular to *B*, horizontal and fixed with respect to magnet; θ_2, axis fixed with respect to axis of valve; θ_3 axis of valve.

Any departure from symmetry of the valve position with respect to *B* causes R_a to increase. The position of minimum R_a ($R_{a\,min}$) corresponds therefore to unique values of θ_1 and θ_2 (θ_{1min} $\theta_{2\,min}$). For this method to be of any value in the measurement of unknown magnetic fields, it had to be shown that the values of θ_{1min} and $\theta_{2\,min}$ can be approached independently of one another whatever the degree of initial asymmetry of the valve position. Thus whatever the value of θ_2, R_a would pass on rotation about θ_1 through a minimum at $\theta_1 = \theta_{1min}$ and then pass through a second and lower minimum on rotation about θ_2 when $\theta_2 = \theta_{2\,min}$. The order of rotation could of course be reversed. It was this final value of $R_{a\,min}$ reached, which was unique and independent of the spatial or electrical history of the valve, that was measured.

A further requirement to be fulfilled was for θ_{1min} and $\theta_{2\,min}$ to be purely spatial co-ordinates (i.e. indicating parallelism of valve axis with respect to *B*) and to be independent of *B*, V_a and I_{a0}. Extensive tests proved these conditions to be satisfied. $\theta_{1\,min}$ and $\theta_{2\,min}$ were repeatable within the accuracy of measurement ($\pm\frac{1}{2}^\circ$) which at one point of the calibration curve with $R_{a\,min} = 0{\cdot}557$ ($V_a = 10$ V, see Fig. 5) corresponded to variations in $R_{a\,min}$ of $\pm 0{\cdot}007$. At this point of the characteristics which coincided with the most rapid variation of $R_{a\,min}$ with respect to *B*, this represented an uncertainty of ± 7 G with $B = 1000$ G, an accuracy not achieved in the calibration of the magnet by other (ballistic) methods. Furthermore, $\theta_{1\,min}$ and $\theta_{2\,min}$ were constant throughout a given cut-off curve (i.e. V_a, I_{a0} constant, B varying) and were also independent of V_a and I_{a0}.

Since, as mentioned earlier, I_{a0} under temperature-limited conditions is difficult to monitor, an operating point had to be selected where $R_{a\,min}$ was relatively insensitive to variations in I_{a0}. Fig. 4 shows such a calibration for values of I_{a0} of 1·5 μA, 28 μA and 1·4 mA corresponding to a range of heater current of 67 to 90·5 mA.

For the calibration of the valve a value of $I_{a0} = 28$ μA was finally selected and inspection of Fig. 4 indicates that a variation of $I_{a0} = \pm 4$ μA, a liberal tolerance as far as ease of measurement is concerned, would not appreciably affect the value of R_a.

The calibration curves are shown in Fig. 5. Apart from $V_a = 5$V plot, the readings did not vary much for reversals of B. For each value and direction of B, θ_{1min} and $\theta_{2\,min}$ were separately determined but within the accuracy of measurement did not vary. Accepting the 10 and 20V plots as useful calibration curves, the range of values of B cover can be considered to be approximately 700—2800 G. Upwar extension of this range could be effected either by an increa in V_a or by smaller inter-electrode clearance. The 5V pl is perhaps too sensitive to field reversals, and also fluctuatio in contact potential during the life of the valve would affe it. Extension to lower values of B should therefore be soug by increase of inter-electrode clearance, rather than by reduction of V_a much below 10 V.

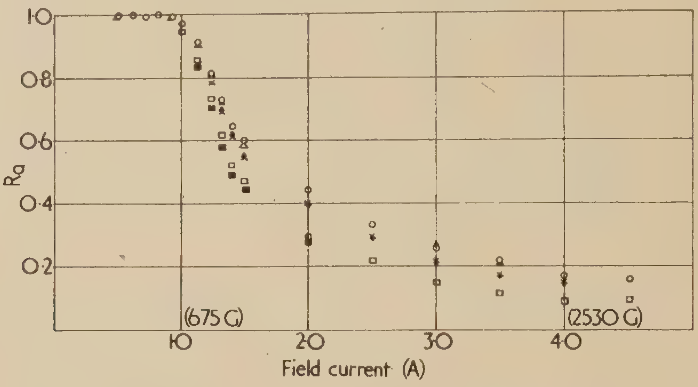

Fig. 4. Dependence of R_a upon I_{a0} for particular valve used

$V_a = 10$V			
I_{a0}	1·5 μA	28 μA	14 mA
$B\rightarrow$	○	▪	□
$B\leftarrow$	△	×	■

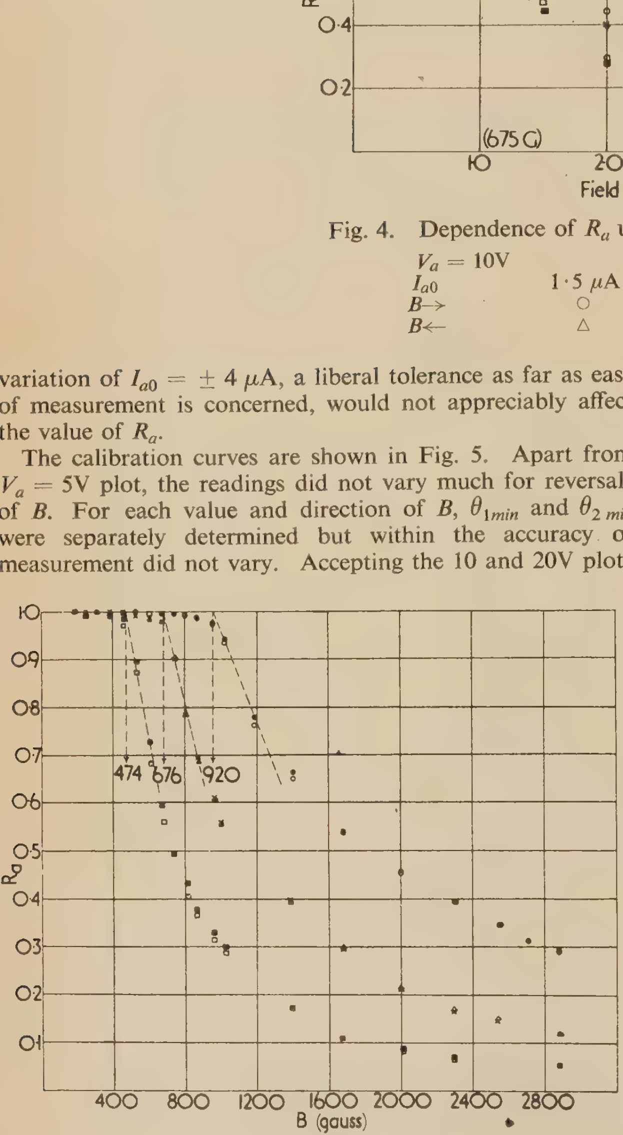

Fig. 5. Calibration curves

$I_{a0} = 28$ μA	$V_p = -0{\cdot}6$ V		
V_a	5 V	10 V	20 V
$B\rightarrow$	■	△	●
$B\leftarrow$	□	×	○
$B_c/(V_a + V_p)^{\frac{1}{2}}$	226	221	209

Of additional interest is the fact that the value $B_c/(V_a + V_p)^{\frac{1}{2}}$ as calculated from the cut-off knee (see Fig. is fairly constant. On the assumption that as far as elect trajectories are concerned the cathode and anode are plan a value of 0·15 mm is obtained for the clearance, which not very different from the nominal value of 0·17 mm.

The cathode of the valve is indirectly heated and t magnetic field due to the heater current can therefore expected to be small. This was in fact observed, values $R_{a\,min}$ not only being insensitive to direction of heater curren but the display of the cut-off curve on a cathode-ray oscill graph proved to be unaffected by a transient interruption heater current, thermal inertia of the system keeping constant.

This method of measurement of B, which is of cour relative, was much used by the author in conjunction with variable gap electromagnet. To calibrate the valve initial the value of B was measured by an absolute method (ballisti use of standard mutual inductance, Grassot fluxmeter ar search coil of known dimensions and number of turns) as function of the energizing field current. The measureme was then repeated with the magnetron diode, a given fie current taken to correspond to a given value of B, care bei taken to avoid hysteresis effects. Repeatability of t magnetron method proved much better than the absolu method of measurement.

The method requires only simple apparatus. All valve even if nominally of the same type, have to be separate calibrated, since small geometrical differences in electro structure would strongly influence the magnetron effe Means of insertion and rotation of the valve in the magnet field could be designed according to circumstances. In a measurement of unknown magnetic fields, knowledge of i approximate direction would be useful so as to make o axis of rotation perpendicular to it. Uniformity of t field B throughout the inter-electrode volume is, of cour med, and the method is only capable of obtaining a sure of the *resultant* of B and that with the valve position metrically adjusted. Unlike other methods it cannot sure cross-fields.

CONCLUSIONS

epeatability of the magnetron effect within very close its makes it very useful in the measurement of magnetic ds. Use of sub-miniature diodes, preferably with indirectly-ted cathodes, is suggested and means of rotating the valve ut two mutually perpendicular intersecting axes with one ight angles to the axis of the valve (the other preferably ng at right angles to B) is required so as to adjust the valve ler given conditions for minimum current flow. The hod of measurement is a relative one and each valve must ndependently calibrated against a known standard. Con-ons should be selected such that the normalized current v R_a is relatively insensitive to variations in cathode ission current. The method can, of course, only measure the resultant of B. For this, as mentioned above, the valve has to be adjusted to a position of symmetry with respect to B which for $B > B_c$ corresponds to minimum current flow.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Langmuir, I. *Phys. Rev.*, **26**, pp. 585–613 (1925).
(2) Linder, E. G. *Proc. Inst. Radio Engrs*, **26**, pp. 346–371 (1938).
(3) Linder, E. G. *J. Appl. Phys.*, **9**, pp. 331–334 (1938).
(4) Harvey, A. F. *High Frequency Thermionic Tubes* (London: Chapman and Hall, Ltd., 1946).
(5) Fulop, W. *Thesis* (University of London, 1956).

A high-resolution grating spectrometer for the infra-red region

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A grating spectrometer designed on an Ebert mounting has been constructed which, with suitable photoconductive cells and a 6 × 6 in. N.P.L. grating, gives a resolution of 0·1 cm^{-1} in the range 6000 to 1700 cm^{-1}. It covers the region 600 to 10 000 cm^{-1} with a single grating and is as simple to operate as a conventional prism spectrometer. It is intended as a high resolution general purpose instrument which will give a performance an order of magnitude better than that of a prism instrument over the main spectral range.

cent developments(1, 2) in the production of highly blazed ielette gratings and improvements in performance of otoconductive and other infra-red detectors have made ssible the construction of infra-red spectrometers of very h resolving power. The design of these instruments must such that the ultimate performance, both in resolution d absolute wavelength determination, is not limited by her optical or mechanical features. These requirements met by the spectrometer to be described which, while t much larger in size than a prism spectrometer and of atively inexpensive construction, yet has a resolution comrable with the most elaborate instruments built. It has en designed to operate with a 6 × 6 in. grating and to ver the range 1 to 15 μ without altering the setting of the ating, thus enabling a permanent calibration to be set up. e wide angle of travel required to achieve this has necessied the use of a long lead screw conforming to a very high ndard of accuracy. The best resolving power obtained so using a 2500 lines per inch grating blazed in the first der at 10 μ has been 60 000 (0·1 cm^{-1} at 6000 cm^{-1}).

OPTICAL DESIGN

Of the large number of possible reflecting collimating tems which may be used it was decided that the Ebert(3–6) tem offered the greatest advantages for the type of spectrometer required. These are briefly: (1) the system is almost completely free from aberration, apart from slight astigmatism for which correction can easily be made; (2) because of its symmetry the system is equally correct for any point along the slit length which is not the case for systems using parabolic mirrors; and (3) the use of only spherical mirrors instead of parabolic mirrors at large apertures results in a considerable saving in cost without loss in performance.

Although the Ebert system is aberrationless for the case of zero order reflexion from the grating, errors arise in other orders owing to the fact that the light falling on the grating is not parallel. This was shown by Fastie(6, 7) to effectively limit the system according to its f number. The initial calculations of Fastie have been extended and lead to the result that the maximum resolving power of the system is given by $\lambda/d\lambda = 43f^4$. Now the theoretical (Rayleigh) resolution of a grating is $d\nu(\text{cm}^{-1}) = 1/2l\sin\theta$, where l is the ruled length of the grating and θ is the angle between the grating normal and the optic axis of the system. Thus for $l = 6$ in. and $\theta = 30°$ (normal blaze angle), $d\nu = 1/15$ cm^{-1}. Assuming that the spectrometer will not be used at wavelengths shorter than 1·8 μ (6000 cm^{-1}) the maximum resolving power would be 6000 × 15 = 90 000 and for this to be equal to $43f^4$ the minimum f/number is 6·7. Thus with 6 in. diameter mirrors, the focal length L would be approximately one metre.

It has been shown by Fastie(7) that for a given source and grating and for a specified resolution the only parameter which can affect the amount of energy emerging from the exit slit is P, the ratio of the slit length s to the focal length L. Now the maximum value of P is itself set by the size of the image s' and the numerical aperture N' acceptable by the detector. Thus if N is the numerical aperture of the spectrometer then the maximum reduction of the slit image on the detector is $s'/s = N/N'$. Now as $P = s/L$ and $N \simeq G/L$, where G is the grating width, we obtain $P \simeq sN/G = s'N'/G$ which for a given value of G is determined purely by the detector. It should also be stated that in practice the value of N' is often decided not by the detector but by the maximum numerical aperture obtainable without serious losses using a reflecting condensing system.

OPTICAL LAYOUT

The optical arrangement of the spectrometer is shown in Fig. 1. The radiation from the Nernst glower is condensed on to the entrance slit A of the pre-monochromator which consists of a 20° back-aluminized potassium bromide prism (face $3\cdot2 \times 4$ in.) used in a modified Ebert system of 16 in. focal length. The slit A is curved to an amount determined empirically so that its image in monochromatic light at about $2\cdot5\ \mu$ matches the curvature of the entrance slit of grating section. In this section two spherical mirrors of 6 in. diameter and 86 in. radius of curvature set on a common centre illuminate the grating with a parallel beam and focus the spectrum on to the exit slit. In accordance with the requirements of the Ebert system the main entrance and exit slits are curved on a circle centred on the grating and of diameter equal to their separation (in this case 9 in.). After emerging from the exit slit the radiation is condensed either on to a thermocouple or a photoconductive cell, selection being made by movement of the mirror M. A 5/1 reduced image of the exit slit is produced on the photoconductive cell D by a spherical mirror of focal length 6 in. in a Pfund mounting. An on-axis ellipsoid C with an image reduction of 7/1 is used with the thermocouple. The components are mounted on a rectangular base in the shape of an inverted lidless box 66 in. long, 21 in. wide and 5 in. high made from $\frac{1}{2}$ in. Duralumin sheet. A cross-plate is included 24 in. from one end both to strengthen the construction and to enable the grating, fore-prism and slit drives to be housed in a closed compartment inside the base. An air-tight cover made of Perspex encloses the optical components and this is normally flushed with dry air to reduce atmospheric absorption. While the advantage of a vacuum spectrometer for the complete elimination of atmospheric absorption cannot be questioned, this is offset by considerations of complexity of operation and cost of construction.

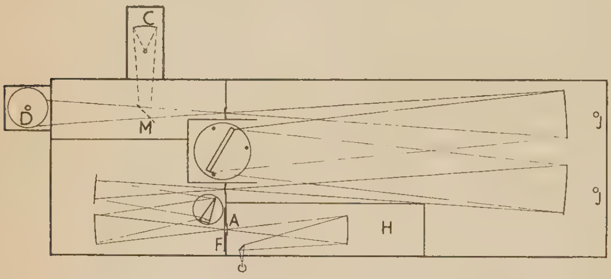

Fig. 1. Optical layout of grating spectrometer

A, entrance slit; *C*, thermocouple condensing mirror; *D*, condensing system for photodetector; *F*, chopper; *H*, Nernst condensing mirror; *J*, *J*, dry air inlets; *M*, mirror.

Slit assembly. Since it is necessary to keep the two main mirrors lying as closely as possible on the same spherical surface, it was decided to focus by moving the whole slit assembly rather than by altering the position of these two mirrors which were set initially to have a common centre. This assembly is accordingly mounted on a sub-frame (12 × 13 in.) shown in Fig. 2. The two jaws of each slit are attached to two arms which rotate independently about a pillar extending upward from the sub-frame. The ar carrying the outer jaw of each slit is coupled to that carrying the inner jaw of the other slit by a kinematic linkage such that both arms rotate by equal amounts in the same direction. To open the slits, drive is applied to the kinematic links by two nuts on a left- and right-hand threaded screw (26 turns/in.). Two tension springs pull the slits shut and stops are provided to prevent over-running and consequent damage to the slit jaws. The driving screw is joined by a shaft and two universal couplings to a calibrated drum on the outside of the spectrometer base giving the slit opening in millimetres. The sub-frame is supported in four slides and can be driven in the direction of the optic axis by a tapered screw acting against springs. This screw serves as the focusing adjustment and greatly simplifies this operation.

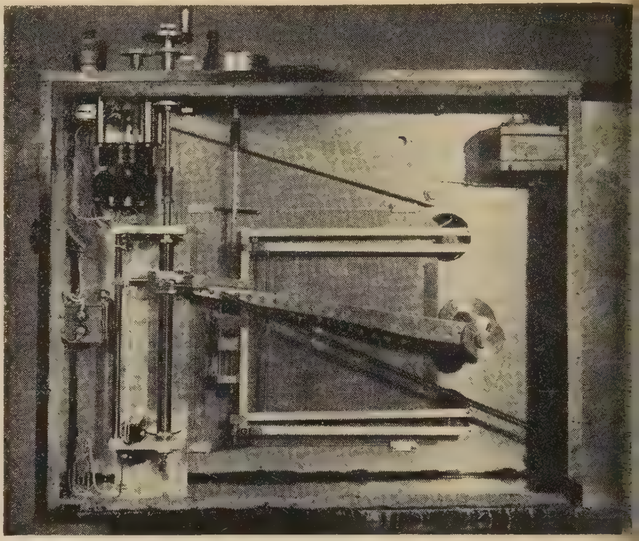

Fig. 2. Underside of spectrometer showing slit and grating drives

Grating mount and drive. In order that there should be no break between the first and second orders in the spectral region covered by the grating the angular travel must be such that $\sin\theta\,(\text{max.}) \geqslant 2\sin\theta\,(\text{min.})$. Now the maximum useful angle of a grating with a 30° blaze is about 45°, thus θ (min. is about 20° and the angular travel must be at least 25°. To achieve this a lead screw with a travel of 8 in. mounted 15 in. from the grating turntable was chosen.

The grating is mounted in a support which stands on three levelling screws, fitting in a hole, groove and flat, on a horizontal rotating table. The face of the grating is perpendicular to a line joining two of the screws. The table itself is attached to a shaft carried in two pre-stressed ball bearings mounted 3 in. apart in a casing screwed to the underside of the base te (Fig. 3). From a cork-lined clutch at the bottom of shaft extends an arm 15 in. long which bears against a on the lead screw. The clutch is to permit easy adjustment the grating angle. The hardened and ground lead screw in. long and has a ¾ in., 26 turns/in. thread. It is sup- ted in two ball bearings, and an end stop is provided by a

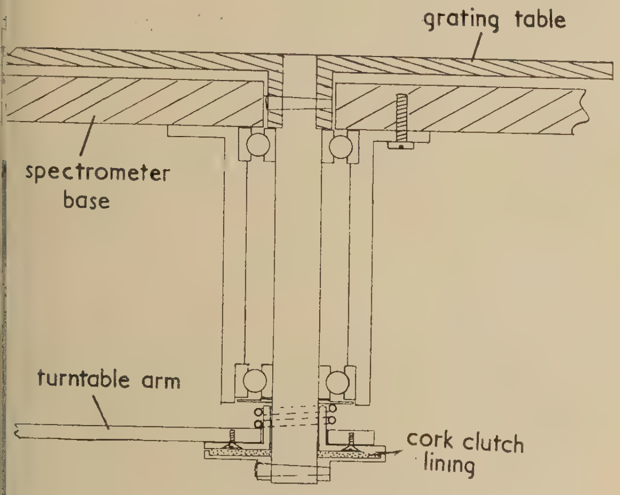

Fig. 3. Grating bearing and clutch

el ball set in one end bearing against a hardened and ished steel flat set accurately perpendicular to the line of lead screw. The phosphor-bronze nut is ¾ in. long and topped from rotating by a 3 in. long arm sprung against a de bar. Two hardened steel pins projecting from the top l bottom of the nut bear against the two arms of a "yoke" ached by a flexible beryllium copper leaf to the end of the n from the grating table (Fig. 4). The effect of this yoke to completely eliminate any "drunkenness" (one-turn iodic error) in the lead screw. A diagonal spring attached the arm keeps a constant pressure between it and the nut any angle of the arm.

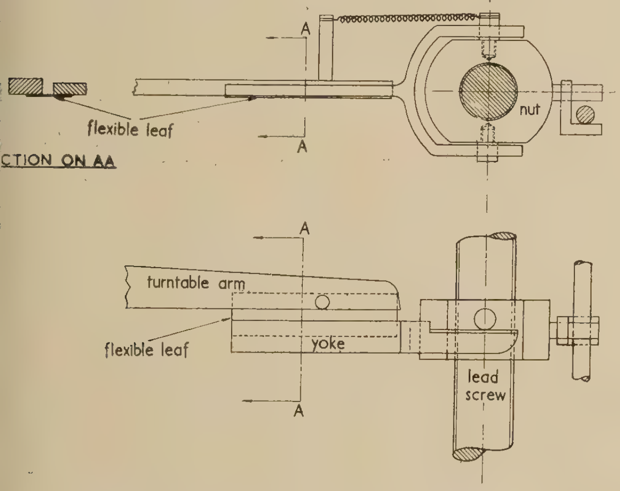

Fig. 4. Flexible yoke coupling turntable arm to lead screw

Two small pins projecting from a wheel at one end of the d screw operate a microswitch to provide calibration "pips" ery half turn of the screw. Drive is provided by a ½ rev/min ersible Synclock synchronous motor. Shafts from this and the lead screw extend through phosphor-bronze bearings to the outside of the spectrometer where they are coupled by a pair of spur gears. These gears are easily interchangeable and provide ratios of 5/1, 3/1, 2/1, 1/1, 1/2, 1/3 and 1/5. A Veeder counter driven from the lead screw shaft records twenty units per revolution of the shaft. Two microswitches connected in series with the drive motor prevent over-running at either end of the screw.

Fore-prism mount and drive. The 20° potassium bromide fore-prism is mounted on a turntable raised 2 in. above the spectrometer base and incorporates a 5 W heater on its underside. The prism table is supported by a shaft passing through a phosphor-bronze bearing attached to the spectrometer base. It is rotated by means of a micrometer head which drives against an 18 in. arm extending from the lower end of the shaft. A clutch is provided for easy adjustment of the prism angle. The entrance slit of the pre-monochromator is mounted on a baffle at *A* (Fig. 1) and has a rotational adjustment to permit exact alinement with the entrance slit of the main monochromator. The slit length is sufficiently long to accommodate the image of a 1 in. Nernst filament. The fore-prism position and the slit widths are adjusted manually.

The spectrometer rests on a 1½ in. sheet of slate supported by six rubber mountings on a heavy wooden table. This renders it substantially free from higher frequency vibrations and no effects of vibration have been observed. It is housed in a room thermostatically controlled to ±2° F. The other features of the instrument, such as the electrical design of amplifiers, etc., are fairly conventional and do not warrant special description here.

PERFORMANCE

The performance of a spectrometer is judged by its resolving power, signal/noise ratio, spectral purity and the accuracy and repeatability of the wavelength scanning system. Between 1·5 and 3 μ (lead sulphide detector) ideal resolution tests are provided by a number of gases (in particular carbonyl sulphide, see Fig. 5) which have bands whose rotational structure converges rapidly to a band head. Lines separated by 0·1 cm^{-1} have been clearly resolved over much of this region with a very low background noise. At 6000 cm^{-1} this is a resolving power of 60000 which is about 70% of the theoretical resolution. Incidentally this is nearly twice the best resolution obtained with the same grating with visible light, which

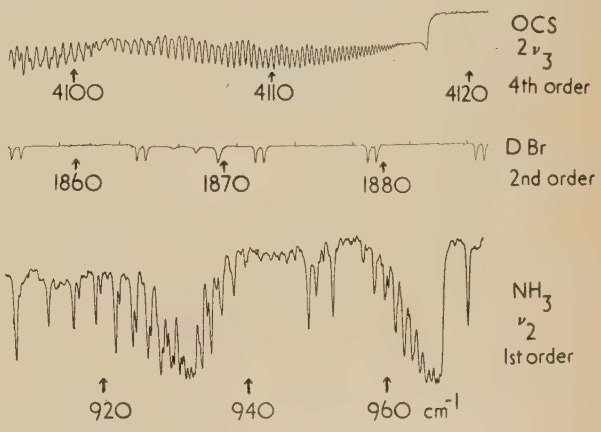

Fig. 5. Resolution tests of spectrometer

indicates that imperfections in the grating that are small compared with the wavelength of the light being used do not materially affect its performance. Between 3 and 5·5 μ (range of lead telluride detector) the best resolution is 0·10 to 0·15 cm^{-1}. Beyond 5·5 μ in the region where thermocouple detectors have to be used there is a further gradual reduction in resolution due to the system becoming energy limited. At 15 μ this has fallen to 0·25 cm^{-1}. A series of spectra in different wavelength regions are shown in Fig. 5 to illustrate the high performances obtainable. With a suitable fore-unit the spectrometer has been operated as a double-beam instrument with little loss in resolution.

As the instrument is effectively a double monochromator the spectral purity is very good. In no case was the proportion of "scattered" radiation greater than a few tenths of 1%. The accuracy of the lead screw was checked by measuring the apparent spacing of the lines of both fundamental and overtone bands of carbon monoxide and hydrogen chloride. The fact that no "drunkenness" greater than 0·00001 in. was detectable indicated the effectiveness of the "yoke" device. The screw was also found to be free from longer periodic errors. The complete range of the grating has been calibrated in terms of frequency against Veeder number. A small but detectable shift in the relative positions of spectral lines and marker "pips" occurs between successive runs of a spectrum. However by running a comparison spectrum of an accurately known standard concurrently with the unknown an appropriate correction can be made. No detectable shifts have been observed from the alteration of slit widths or from movement of the detector or source.

To sum up we should like to stress the fact that the performance of this spectrometer has demonstrated that high resolution can be obtained throughout the range 600–6000 cm^{-1} with a single grating using appropriate orders. This together with the use of a long precision lead screw enables the spectrometer to be used over the whole range and eliminates the need for recalibration or readjustment which is necessary when gratings (or prisms) are changed. Hence the instrument is almost as simple to operate as a standard commercial prism spectrometer while giving a very much higher resolution. It should be noted that the theoretical resolution limit of a grating does not depend on the line spacing but only on the width of the grating. Since we have shown that theoretical resolution can be approached using a wide line spacing grating in high order, it follows that there is little to be gained by using a narrow line spacing grating in low order, and thus sacrificing the wide wavelength range. However, the long wavelength grating, when used in a high order, has the slight disadvantage of a narrower useful range in any one order.

In the past because of limited resolution it has not been possible with prism spectrometers to obtain true values of infra-red absorption coefficients of solutions similar to those available in the ultra-violet region. With the present instrument the spectral slit width is such a small fraction of the normal band widths that no such difficulty should be encountered. Thus the difficulty which now exists of transferring quantitative data from one instrument to another should disappear.

ACKNOWLEDGEMENTS

We wish to record our indebtedness to Dr. L. A. Sayce and Mr. A. Jackson of the National Physical Laboratory for making available a suitable grating for this instrument, also to Messrs. P. Heaver and S. Guttmann for the high degree of technical skill they displayed in its construction. Our thanks are also due to the Department of Scientific and Industrial Research and to the Hydrocarbon Research Group of the Institute of Petroleum for financial support for the project and to the Radar Research Establishment, Malvern, for the loan of a photoconductive cell.

REFERENCES

(1) SAYCE, L. A., and JACKSON, A. *Molecular Spectroscopy*, p. 54 (London: The Institute of Petroleum, 1955).
(2) DEW, D. G., and SAYCE, L. A. *Proc. Roy. Soc., A*, **207**, p. 278 (1951).
(3) EBERT, H. *Wied. Ann.*, **38**, p. 489 (1889).
(4) CZERNY, M., and PLETTIG, V. *Z. Phys.*, **61**, p. 792 (1930).
(5) TETLOW, K. G., MCAUSLAN, J., BRINLEY, K. G., and PRICE, W. C. *J. Sci. Instrum.*, **28**, p. 161 (1951).
(6) FASTIE, W. G. *J. Opt. Soc. Amer.*, **42**, p. 641 (1952).
(7) FASTIE, W. G. *J. Opt. Soc. Amer.*, **42**, p. 647 (1952).

Modifications to a travelling microscope used for measuring X-ray powder photographs

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[*Paper first received* 8 *August, and in final form* 16 *September*, 1957]

A travelling microscope has been adapted for measuring powder photographs. The cross-hairs in the microscope eyepiece were removed and the reference mark was obtained from a light spot thrown on the photograph from a projector clamped to the barrel of the microscope. Cross-hairs seen in silhouette tend to obscure faint lines on the photograph and prevent their measurement. The light spot eliminates this effect, allows change of magnification for measuring different lines without moving the reference mark, eliminates parallax and allows the use of a binocular eyepiece. These features reduce eyestrain while measuring a photograph and improve the accuracy of measurement of faint or diffuse lines. The photograph is illuminated by a short fluorescent tube, the light of which is cooler and "harder" in quality than that of filament lamps.

Means are described of adjusting the light intensity of the tube over a wide range.

n measuring X-ray powder photographs with a travelling oscope, the effect of the cross-hairs is well known and often been described.(1) When using the cross-hairs in + position faint lines tend to disappear behind the cal wire as it approaches their centres, although the wire uch narrower than the lines; the × position is then pre- d. One finds that this reduces, but does not completely inate the effect. Moreover, the × position has the lvantage that attention is concentrated at the point of section of the wires. One thus loses the integrating effect inable in the + position, whereby the centre of the line stimated over an appreciable length of it. Any line tiness or minor film defects then more readily introduce surement errors, which appear plainly as increased er, not in the actual measurements but in the calculated lts. Positions intermediate between + and × do not in the integrating effect. Changing from + to × posi- s involves moving the point of reference, so that strong faint lines must be measured separately, although this be avoided by special cross-hairs with both positions lable.

he authors believe that the underlying cause of this effect e inability of normal sight to appreciate fine detail over a e range of contrasts. A vertical cross-hair then masks a t line, not by its bulk but by its blackness, which distracts ntion from the fine tone-gradations of a faint line. This ct is common to any reference mark seen in silhouette. example, in measuring line positions with a Perspex r, the edge of which is laid along the centre-line of the tograph, one finds that faint lines clearly visible without ruler are often invisible with it, even on that part of the tograph which the ruler does not obscure. This is ibuted to the blackness of the graduations on the ruler.

ees(2) describes an alternative reference mark in the form light-spot projected on to the photograph to be measured. device is only suitable for an instrument in which the tograph is moved relative to a fixed microscope. The hors use a similar method but the modifications to the elling microscope described here are applicable to any rument. Confirming Lees, the cross-hair effect is entirely inated with this reference mark if the intensity of the t-spot is adjusted until it is only just discernible on the hter portions of the field of vision in the microscope. At setting it does least to increase the contrast-range of the l of vision, agreeing with the explanation above. A bright rence mark is thus fundamentally more suitable than a k one for measuring the position of dark objects on a t ground.

DESCRIPTION OF THE MICROSCOPE

The instrument, shown in Fig. 1, is based on a Model 14 travelling microscope by The Precision Tool and Instrument Co. Ltd.; this is a vernier instrument reading to 0·01 mm over a 30 cm range. The microscope *A* is fixed to a carriage *B* which allows it to move perpendicular to the main traverse over a 7½ cm range, read to 0·01 mm. The photograph *C* is laid on a glass strip on a super-stage *D*, fitted with levelling screws, which has been built over the main-stage.

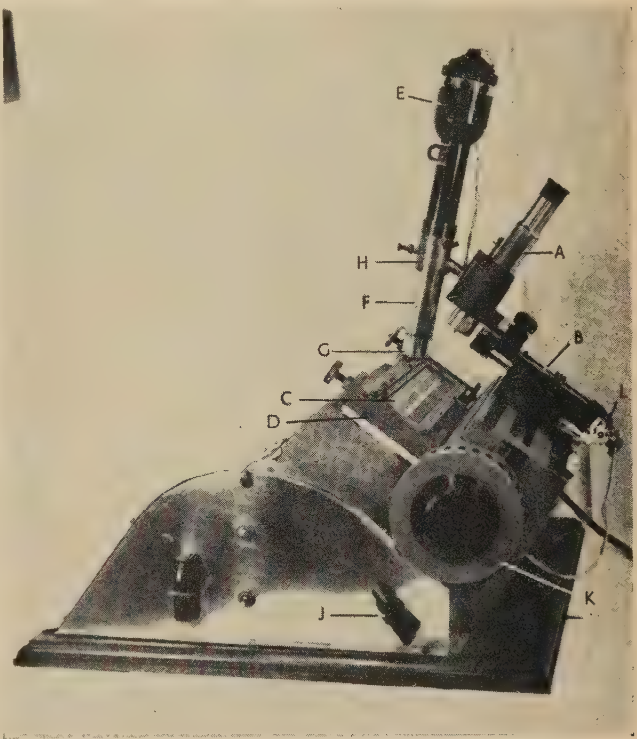

Fig. 1. The travelling microscope with projector attachment

As shown here, a Ramsden eyepiece with the cross-hairs removed is used in the microscope and the reference mark is obtained as a light spot on the photograph from the projector attached to the microscope mounting. In the simple model shown, the lamp housing *E* is taken from an old mirror galvanometer spotlight, and uses a 4 V, 8 W projector lamp.

The housing is a sliding fit over the brass tube *F*, which carries a diaphragm with a fine slit (made from metal foil) at its upper end. There is a converging lens *G* at the lower end of tube *F*, the lens mount being a sliding fit in the tube and retained by a grub screw. The lens focuses a reduced image of the slit in the diaphragm on to the photograph. A condenser lens above the slit somewhat concentrates the light from the projector lamp. The projector is clamped to the microscope in a loosely fitting ring mount *H* by five screws with locknuts, which can be adjusted to bring the projected light spot into the centre of the microscope field.

The dimensions of the projector are limited by the need to provide headroom above the microscope eyepiece and to clear the microscope objective; this in turn limits the reduction of the image of the slit to about ×2. Greater reduction might be an advantage, obtainable by using two projection lenses; an efficient condenser, bringing the image of the lamp filament to a focus on the back of the diaphragm, would also increase the available image brightness. The present arrangement is satisfactory if the room is not too brilliantly lit; this is in any case highly desirable.

The brightness of the projected image can be adjusted by the rheostat *J* in the projector lamp circuit, so as to be just comfortably discernible above the general background blackening of the photograph; this setting is correct for both strong and faint lines. The size and shape of the reference mark can be chosen at will; shapes |, +, → ←, -|- are convenient, the first being most generally useful, cut to the length over which it is desired to integrate in estimating the line position; the last shape is useful when the instrument is used as a co-ordinate microscope. A typical light spot on a diffraction line on an X-ray powder photograph is shown in Fig. 2, which was obtained with a photomicrograph camera attached to the microscope eyepiece of the instrument.

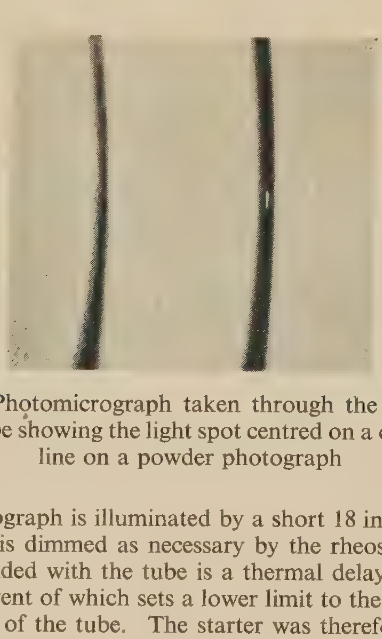

Fig. 2. Photomicrograph taken through the travelling microscope showing the light spot centred on a diffraction line on a powder photograph

The photograph is illuminated by a short 18 in. fluorescent tube. This is dimmed as necessary by the rheostat *K*. The starter provided with the tube is a thermal delay switch, the hold-on current of which sets a lower limit to the current and light output of the tube. The starter was therefore replaced by a press-button switch, allowing the tube to be dimmed to very low intensity. The rheostat was also modified since one sufficient to give adequate dimming and to carry the current at nearly full intensity would be impracticably bulky. The connexion between the winding and the terminal strap at the full-on position was therefore broken and a 1000 Ω, 5 W current-limiting resistor was inserted; this gives a barely perceptible "jerk" in the initial dimming of the tube.

The air-gap between the main-stage and the super-stage is used to insert additional diffusion screens as required and a mask to cut out light from the unexposed margin of the photograph. In this position they can be inserted or changed without moving the photograph. The authors have also experimented with colour screens inserted in the air-gap (e.g. from darkroom safelights); some observers find a distinct improvement but the effect is highly subjective.

The microscope vernier is illuminated by a 6 V, 3 W car indicator lamp *L* held in Terry clips on insulated bushes in an aluminium reflector, and is viewed through a lens. The instrument is mounted on a baseboard, tilted for convenience in use and to accommodate the fluorescent tube. The electrical gear for the various low-voltage lamp circuits is contained in the aluminium case. No provision for ventilating louvres in the case has been found necessary.

ADVANTAGES OF THE MICROSCOPE

The light-spot as reference mark eliminates the cross-hair effect. It also eliminates parallax so that focusing is not critical. The authors have found increased accuracy of measurement of both strong and faint lines, and definitely decreased eyestrain. Being already accustomed to cross-hairs, increased accuracy in measuring strong sharp lines was not very noticeable to the authors, but became at once apparent in tests with inexperienced observers by comparison with the use of cross-hairs; this result may be a valuable feature of the instrument.

Divorcing the reference mark from the microscope lenses also allows one to change the magnification to suit the line being measured without moving the mark. Best results on strong sharp lines are obtained when the greatest convenient magnification is used, about ×4 for normal X-ray film. For more diffuse lines, measurements may be more accurate and consistent at lower magnification than ×4 and it is also less easy to see faint lines at large magnifications. With both lenses removed, the film can be viewed down the microscope barrel without magnification. In principle the magnification could be adjusted to suit each line in turn. This facility is valuable where it is necessary to measure a few weak lines to complete results obtained mainly from strong sharp ones, or to measure diffuse high-angle lines from poorly crystallized material as well as the sharp lines at medium Bragg angles.

It might be thought that the reference mark is more vulnerable to movement during a set of measurements than are cross-hairs. The authors regularly measure the positions of the "knife-edges" on powder photographs, before, after and often during, a set of measurements, and find them reproducible to 0·01 mm, even when the microscope lenses have been changed during measurement. However, such check measurements are obviously desirable, even with cross-hairs.

The fluorescent tube is superior to filament lamps, both as to its lower power and cooler running, which allow the X-ray film to come to thermal equilibrium very quickly on the microscope stage, and for the "harder" quality of its light. The ability to adjust its intensity over a wide range is very desirable for the comfort of the observer, and also for the following effect: one finds that in bright light one tends to measure the peak density of a line and in dim light its centre of gravity. The requisite brightness or dimness depends on the intensity of the diffraction line, and if this has an asymmetric profile the two results may be very different. This effect can be put to good use in measuring partly resolved α_1, α_2 doublets, which in bright light give the position of the α_1 component and in dim light are measured as if unresolved.

e final drawback associated with a single eyepiece has
tly been eliminated—namely the strain of keeping shut
ye not in use or of tolerating the direct glare from the
ograph. Removing the cross-hairs allows one to incor-
te a binocular eyepiece. Standard binocular eyepieces
re a greater tube-length than monoculars and are not
ally available at magnifications as low as ×4. Messrs.
Ltd. have adapted a standard model with ×6 oculars
ttaching a telescope lens of suitable focal length to the
iece tube. The assembly gives a fixed magnification of
t ×4. Using both eyes has given a definite improvement
as to freedom from eyestrain and in clarity of vision.

ACKNOWLEDGEMENTS

Thanks are due to Mr. A. Shail for help in modifying the travelling microscope and to the North Thames Gas Board for permission to publish this paper.

REFERENCES

(1) e.g. Henry, N. F. M., Lipson, H., and Wooster, W. A. *The Interpretation of X-ray Diffraction Photographs*, p. 171 (London: Macmillan, 1951).
(2) Lees, C. S. *J. Sci. Instrum.*, **32**, p. 17 1955).

An oxidizing atmosphere furnace for use with an X-ray diffractometer*

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[*Paper first received* 24 *July, and in final form* 29 *October*, 1957]

A resistance furnace assembly to fit the Norelco diffractometer is described. It makes possible the investigation of rigid specimens or powders in controlled atmospheres or vacuum.

order to study bar-shaped specimens in oxidizing
ospheres or vacuum by X-ray diffraction, a resistance
ace has been developed for use with the Norelco X-ray
actometer (by North American Philips Co.). In its
ent form it has been used at temperatures up to 950° C,
could be modified for temperatures up to 1600° C. It
given satisfactory service with oxygen atmospheres for
teen months. Inert atmospheres and vacuum have also
used and the use of some reducing or corrosive atmo-
eres should be possible. It is especially useful for the
stigation of the sequence and rate of formation of surface
rs, such as are produced during the oxidation of ferrous
ys.(1)

hen sufficient material is available, specimens are usually
ared as bars approximately 1·25 × 0·6 × 9·0 cm, with
sides. If only a small metal sample about 1 × 2 cm is
ilable, this is screwed (with slots for expansion) to a
ped base, and bar and specimen are ground flat together.
surface contamination of the specimen can afterwards
removed by careful etching. Powder samples can be
unted in a bar containing a shallow depression. Heat
duction is very effectively reduced by slotting the bar
r one end. It is clamped at this end, outside the heater,
stainless steel mount, described below (*G*, Fig. 2).

he design is based on that of Chiotti,(2) who used a
talum heater providing high temperatures but requiring
inert atmosphere and relatively heavy leads. The principal
nges are in heater construction, cooling arrangements, and
cedure for alining the specimen in relation to the
iometer.

metal bar specimen in an oxygen atmosphere can be
ed to 800° C in five minutes with a power input of about
W, current 13 A, or can be cooled from 800 to 80° C
ive minutes. The temperature is automatically controlled
is stable during twenty-day experiments.

The furnace is U-shaped in section (Fig. 1). A soft ceramic (e.g. Alundum) tube 7·5 cm long and 3 cm internal diameter is the most convenient base. One side is cut off, leaving a lengthwise opening 1·5 cm wide. It proved easier to cut this former than to mould it. A hacksaw blade is used to cut grooves in the tube, parallel to its length, spaced more closely together near the opening to provide for more uniform heating. Platinum 10% rhodium wire, 0·09 cm diameter, is wound in these grooves in a continuous spiral and the ends of the wire are doubled to form the electrical connexions. Both sides of the furnace are coated with a thin layer of alumina cement. Small cones of cement are placed on the outside to maintain a gap of about 2 mm between the furnace and the radiation shield. A silver radiation shield 0·05 cm thick is wrapped around the furnace. If higher temperatures were needed gold, platinum or a heat resistant alloy could be used for the shield. The electrical connexions are made to two threaded posts which also support the heater and shield (Fig. 1). Each carries a small metal block. This block contains a set-screw and is drilled to receive a rod

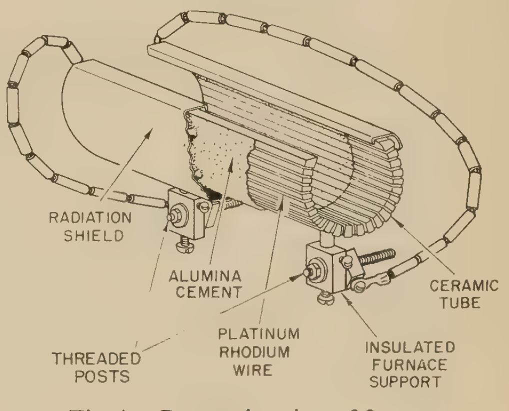

Fig. 1. Perspective view of furnace

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Now at Department of Physical and Inorganic Chemistry,
versity of Adelaide, South Australia.

which is bolted to one end of the radiation shield. The blocks are thermally and electrically insulated from the threaded posts by ceramic bushings and mica washers, and are fixed in place by lock-nuts. This arrangement allows the position of the heater to be adjusted in two dimensions. The posts are secured to the specimen-chamber base (*B*, Fig. 2) by lock-nuts. Ceramic bushings are again used for insulation, while a vacuum seal is made by a compressed Tygon washer. All these supporting members for the heater are made of stainless steel.

The specimen chamber (Fig. 2) consists of a hollow-walled cover *A* and base *B*, both of which are water-cooled. The parts are machined from 65 ST aluminium. A 1·3 cm slot *C* is milled in the cover for the incident and diffracted X-rays. This slot is covered by a 0·006 cm aluminium window which is held in position by wire clamps and sealed with Apiezon W wax. Much thinner foil can be used if vacuum work is not planned. This slot extends somewhat beyond a half-circle to permit the furnace to be alined to the X-ray beam. A bridge is left at the mid-way point to provide extra cooling and support for the aluminium window. A water channel *D*, cut in cover *A*, is covered by a brass band which is pulled tight by a screw working in blocks brazed to the ends of the band. A thin cork strip makes a convenient gasket. Cooling water enters the channel through a nipple *E* directly opposite the bridge in the X-ray slot; it then passes into the hollow top portion through holes *F* drilled at positions located 80°, 180° and 280° from *E*. The diameters of the holes are chosen so that about half the flow goes through the hole in the 180° position, that is, in the bridge across the window. The water leaves the top through the nipple *L*. The top of the furnace cover *A* is a shrink fit on to the main portion of the cover. The base *B* is hollowed out and is finished with a flat plate screwed into place. The flanged bushings for furnace supports, thermocouples and gas outlet *N* are press fits. O-ring vacuum seals are provided where necessary and water joints are sealed with a rubber cement suitable for bonding to metals.

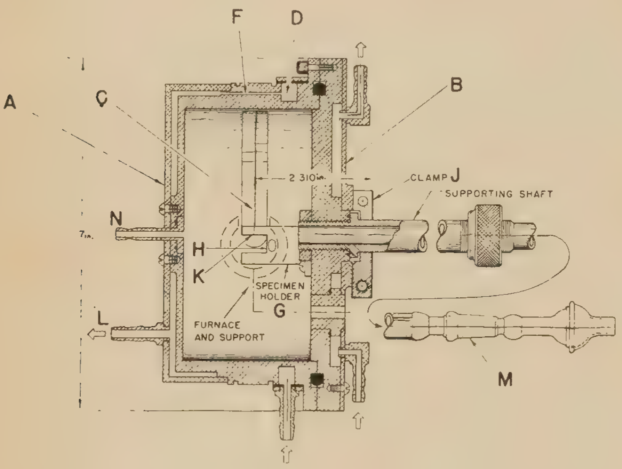

Fig. 2. Cross-section of assembled specimen chamber. For extra clarity the position only of the furnace and its supports is indicated by dotted lines

The stainless steel specimen holder *G* must be accurate made and assembled so that the flat upper face *K*, again which the specimen is located, lies along the diameter base B. The bar-shaped specimen or specimen-container held against the face *K* by a screw passing through other side of the specimen holder. The inner face *H* of th slot locates a 1·25 cm specimen symmetrically in the centr of the X-ray beam—narrower specimens can be locate against a centre mark. A hole about 0·3 × 0·6 cm is bore through the specimen holder to take twin-bore cerami tubing carrying a heavy gauge chromel-alumel contr thermocouple, the end of which is located close to the centr of the specimen and between the specimen and furnace. Th specimen temperature is measured by a 0·019 cm diamete platinum–platinum 10% rhodium thermocouple placed in small hole or slot in the specimen immediately adjacent the area irradiated by the X-ray beam. It is calibrat against the known thermal expansion of a standard silv specimen.

The clamp *J* connecting the furnace and the diffractome is made from stainless steel which should be about 0·95 thick for satisfactory strength. The dimensions of specim holder, base and clamp are such that when the assemb specimen chamber is pressed against the bronze bearing the diffractometer the specimen is in the centre of the bea (5·87 cm for the present case). The alinement of the whol assembly on the diffractometer is direct. A metal bar wit its upper face ground flat is placed in the specimen holder with two narrow strips of 0·001 cm aluminium foil betwe the flat face *K* of the specimen holder and the bar. A te porary lead shield limits the transmitted X-rays to the narr beam passing between the face *K* and the bar. The assem is now mounted on the diffractometer, which has already b carefully alined in the usual manner. The Geiger counter set to zero position and the furnace assembly adjusted give maximum response from the counting circuits. Th clamp *J* is then tightened. It is found that the furnace a ordinary specimen holder are interchangeable.

The gas and vacuum line is glass. A standard ground glas joint *M* is cemented to the end of the stainless steel sha which carries the furnace. This joint is then connected two ground glass ball and socket joints to the gas and vacuu line.

The use of the high temperature thermostat in conjunctio with a continuous-recording diffractometer has proved value in the study of the kinetics of solid-gas reactions, since it has been possible to apply corrections for X-ra absorption. The method should also be of use for the stud of certain solid state reactions.

ACKNOWLEDGEMENT

The authors thank Mr. E. Niman who constructed th specimen chamber.

REFERENCES

(1) Kennedy, S. W., Calvert, L. D., and Cohen, M. *Tra Amer. Inst. Min. Metall. Pet. Engrs.* In press.

(2) Chiotti, P. *Rev. Sci. Instrum.*, **25**, p. 683 (1954).

The recording of pressure distributions in porous media during fluid flow experiments

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[*Paper first received* 24 *June, and in final form* 31 *July*, 1957]

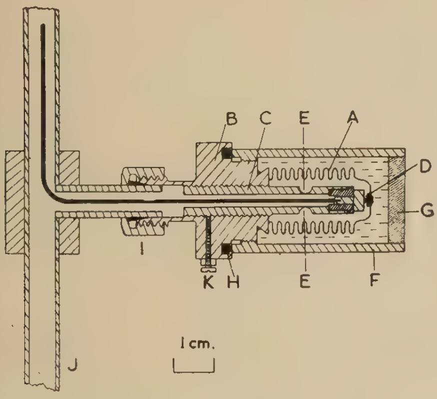
A null-point method is described of recording in a short time interval pressure distributions in in a porous medium during fluid flow experiments. Small cells, buried at numerous points in the porous material, measure the pressure distribution which is recorded in a separate laboratory.

INTRODUCTION

iments are being conducted in a special laboratory(1) a method of recording pressure distributions to solve flow problems in porous materials. The method ys small cells buried in the porous material. These r when the external hydraulic pressure obtaining in the ial at the points where the cells are buried are balanced steadily increasing applied internal air pressure. The ing pressures are recorded in a separate laboratory.

THE PRESSURE MEASURING CELL

construction of the small cells employed is shown in agram. A "hydroflex" metal bellows *A*, closed at one s sealed at the other to a brass seating *B*, through which eaded a plug *C*. The latter terminates in an insulated um-iridium contact *D* which can make contact with a



The pressure measuring cell

ar one on the closed end of the bellows. The lead from nsulated contact passes down the centre of the plug while netal bellows provides a return lead from the other ct. Air is supplied to the interior of the bellows also gh the centre of the plug *via* small holes *EE*. The ws is contained in a brass chamber *F* which affords ction from the porous material while allowing the ge of water through a sintered glass filter *G*. The bellows s subjected externally to the hydraulic pressure obtaining material, while internally it is subjected to a gradually asing air pressure from a controlled source in the atory. The two platinum-iridium contacts blow apart when the external and internal pressures differ by a value governed by an initial adjustment of the plug, and this break in circuit is recorded automatically on continuously moving recording paper. In order that the cell will measure the negative pressures which occur above the phreatic surface as well as the positive pressures which occur below the water table, water must be contained round the bellows and be continuous with the water in the surrounding unsaturated material. This was achieved by making an air-tight seal between the brass chamber and bellows seating by means of an O-ring *H* and sintering very fine glass beads (less than 0·01 mm in diameter) for the filter. When installed in the porous material with the protecting chamber full of water, suctions of the order of 70 cm of water can be imposed before air enters the chamber.

The cells are joined to short lengths of copper tubing by means of "Kontite" fittings *I* (which make an air-tight seal), which protrude at right angles from a brass standpipe *J*. The standpipe forms part of the air lead to the cells while the leads from the contacts pass out of it at the top through sealed holes. The arrangement of the cells on the standpipes, which are designed to stand vertically on the bottom of the experimental tank, and the spacing of the standpipes may be chosen so as to give any desired distribution of cells in the porous medium, for example, in order to give a greater concentration of cells where the pressure gradient is large.

Before the standpipes are buried in the porous material, the plug of each cell is adjusted and locked in position by means of the grub screw *K* so that the contacts are blown apart at approximately a specified pressure when the bellows is in the free atmosphere. In our experiments with sand as the porous material, it is convenient to make this pressure about 35 cm of water, since no greater suctions are experienced. The surrounding filter chambers are fitted under water to the bellows seating so that water is contained round the bellows and air excluded. The cells are then ready for installation. Each standpipe, containing up to ten cells, is buried in the porous material by augering an eight-inch hole in the latter, lowering the standpipe in it and then carefully filling it in after the standpipe has been positioned and made vertical with a plumbline.

THE LABORATORY APPARATUS

In a laboratory separate from the experimental tank, the steadily increasing air pressure which is applied to the interior of the bellows is fed from a high pressure reservoir *via* a reducing valve and is measured by means of a water manometer. The rising water meniscus short circuits electrodes which are spaced at intervals up the manometer tube and which form the input of a one-shot multivibrator. The output from the latter is recorded on the same chart as the breaks in cell circuits, thereby providing pressure calibrating marks.

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REMARKS

Because of the arbitrary setting of the plugs of the cells initially, the system must be calibrated. In our case this is conveniently done by ponding the surface of the experimental tank, since in the ponded static case the pressure everywhere is known.

The expansion of the bellows involved in the opening of the pair of contacts, and thus the volume of water displaced from the protection chamber into the porous material, is so small that the apparatus in fact constitutes a null-point tensiometer and truly records the hydraulic pressure at the point in the medium without itself influencing that pressure. In our case the pressure in one hundred cells can be increased steadily and uniformly in a time period of as little as ninety secon These two facts permit the study of non-steady state flo problems. The overall error of the apparatus is of the ord of 0·5 cm head of water.

ACKNOWLEDGEMENTS

The development of the apparatus, which has formed pa of the programme of work of the Unit of Soil Physics, h been carried out by the authors during the last six yea under the directorship of Dr. E. C. Childs. They are indebt to Mr. H. Forecast for the construction of much of t apparatus.

REFERENCE

(1) Childs, E. C. *Proc. Instn Civ. Eng.* (III), **2**, p. 1 (1953).

A simple method of monitoring ultra-violet light

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A simple monitor has been developed for indicating the progress of solarization of the walls of low-pressure mercury discharge tubes. The intensity of the Hg 5461 Å radiation is compared with the green emission from a phosphor excited by Hg 2537 Å radiation. An intensity match of these two greens can be arranged to occur when the solarization has reached a predetermined point. Other applications of the principle are discussed.

In many industrial and medical applications of ultra-violet light, the intensity of useful radiation has to be monitored to ensure that it is above a given level. This can be done by separating the particular effective ultra-violet region from other radiation in the ultra-violet and visible regions and measuring its intensity by some detector sensitive to this wavelength. This may be done conveniently in the near ultra-violet or visible portions of the spectrum.

Low pressure mercury vapour lamps are usually employed as the source of ultra-violet light. While there are a number of suitable and reasonably inexpensive detectors sensitive to the 2537 Å mercury line, there appears to be no readily obtainable and practicable filter for isolating this line. If elaborate apparatus is to be avoided, the difference between two readings is generally employed, i.e.:

(1) measurement of 2537 Å intensity + other incidental radiation;
(2) measurement of the incidental radiation with the 2537 Å line eliminated.

The 2537 Å line is easily eliminated by a glass filter opaque to this wavelength but transparent to higher wavelengths. One such method is that used by Luckiesh and Taylor.(1,2)

In many uses of ultra-violet, it is desirable that the monitoring apparatus be particularly simple, presenting its reading on a single meter, or as a "Yes-No" reading, in order that it may be used by an unskilled operator. For example, a nurse or a factory employee should be able to read the monitor of an ultra-violet water sterilizer, to ensure that the germicidal ultra-violet is sufficiently high to kill all germs at the water flow rates used.

The following simple monitor was therefore evolved to check intensity of 2537 Å radiation from a low pressure mercury discharge tube. The glass envelope of the mer discharge tube used is originally transparent to 2537 radiation. With continued use, the glass becomes solariz i.e. absorbent in the 2537 Å region, but it is still quite tra parent in the visible region. The monitor works on principle of two adjacent fields of light, one illuminated visible light and the other mainly by ultra-violet light, bei of equal intensity at a given ratio of ultra-violet to visib intensity. Above this balance ratio the ultra-violet side brighter, and the operator knows the lamp is performi satisfactorily. Below this limit, the ultra-violet side will the darker, and a more sophisticated check of the performan of the lamp is needed, or it is discarded and a fresh tu inserted. If the current through the lamp remains consta we make the (reasonable) assumption that the visible radiati does not change and use it as an intensity standard again which to compare the 2537 Å radiation.

The monitor is illustrated diagrammatically in the figu The low-pressure mercury discharge tube, a Westinghou 30 W "Sterilamp" *M*, emits strongly at 2537 Å, and a emits various lines in the nearer ultra-violet, notably 3650 and in the visible. *R* is a matt grey-white card; *L* is a simi matt surface, coated with a phosphor which luminesc strongly in the green region when illuminated by 2537 radiation. Both *R* and *L* are mounted on a backing pla inclined at about 45° to the line of incidence of light from *F* is a green filter, through which *R* and *L* may be viewed. and *L* are inclined so that no specular glare comes through t filter *F* to the operator's eye. The junction between *R* a *L* is made as sharp and clean as possible, to avoid a da line running between the two patches, and consequen lowering the contrast sensitivity of the observer. A shutt *S* excludes ultra-violet light from the monitor when t er is not checking intensity, to prevent deterioration of uminescent material under prolonged ultra-violet tion. A viewing tube in the form of a metal elbow ts the elements in the correct position with respect to e *M*. In our version, *R* and *L* are about 3 in. from d mounted on a card, which slips into position in a

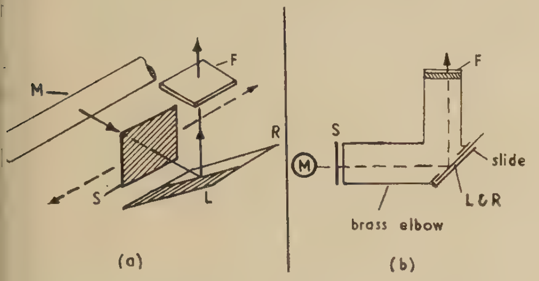

Diagram of monitor

I_{UV} be the intensity of the 2537 Å radiation, and for fication, let it be assumed that this is the only ultra- radiation present. (The luminescent surface *L* is itive to 3650 Å light.) Let I_G represent the intensity of g green line at 5461 Å falling on *L* and *R*. Let the ncy of conversion of I_{UV} to green radiation by *L* be *l* $_L$ and r_R be the diffuse reflectivities of *L* and *R* respec- in the green. For simplicity, the filter *F* is assumed to ll "green" light and no other.

brightness of *L* under combined 2537 Å and green ion from *M* appears as seen through *F* to be

$$B_L = K(l \,.\, I_{UV} + r_L \,.\, I_G) \tag{1}$$

e brightness of *R* to be

$$B_R = K(r_R \,.\, I_G) \tag{2}$$

K is a constant depending on the geometry of the atus, and is the same for both *R* and *L*.

two surfaces are of equal brightness when

$$l \,.\, I_{UV} + r_L I_G = r_R \,.\, I_G \tag{3}$$

$$(I_{UV}/I_G) = (r_R - r_L)/l \tag{4}$$

of course, can only be attained if $r_L < r_R$, since all the ities are essentially positive. The parameters r_L, r_R can be adjusted to make $B_R = B_L$ at a given ratio of I_G). The reflectivity of r_R of the matt surface *R* is ned by its "greyness" which can easily be varied. The escent efficiency *l* of *L* is a property of the luminescent ial used and its dispersion over the surface of the rate. The diffuse reflectivity r_L is determined by the tivity of the luminescent material in the green, the t to which it covers over the surface, and the colour of nderlying substrate. For instance, if white filter paper d as the substrate, on to which luminescent paint is spread, r_L may be quite high. This value may be ly reduced by making the substrate black.

our trial apparatus, the surface *L* was produced by ing or spraying thinned luminescent paint on to ened filter paper. Day-Glo signal green (by Browne Pty. Ltd., Melbourne), such as is used for advertising rs, was found effective. The surface *R* consisted of filter , which might be slightly darkened, if necessary, by dipping it in, or spraying on, Indian ink diluted to appropriate strength with water. No doubt *R* and *L* could be produced by standard printing techniques.

To set the ratio I_{UV}/I_G at which $B_L = B_R$, use is made of a filter which will pass the appropriate proportion of ultra-violet and practically all the visible light. Various grades of glass and cellophane were found useful for this purpose. Cellophane is a useful material for the filter as it can be obtained in a number of grades and thicknesses, transmitting in the range 0–60% at 2537 Å, and transmitting almost all the visible light. The transmission at 2537 Å and in the visible was checked with a spectrophotometer. For example, if it is permissible for the ultra-violet intensity to drop to 30% of that from a new lamp, a glass or cellophane filter is chosen which will pass about 30% of the 2537 Å radiation and practically all the visible. This filter is placed between *M* and *S*. It has similar properties to the tube walls when solarized. The parameters r_L, r_R and *l* are varied as described above so that $B_R = B_L$ at this ratio of (I_{UV}/I_G), using a new lamp.

It has been assumed in the foregoing that *L* and *R* are the same colour when viewed through the filter *F*. In practice the luminescence from the surface *L* due to 2537 Å will constitute a spectrum continuous over a range of wavelengths. In addition, *R* will reflect all the other visible spectral lines from the discharge tube, and *L* will do so to a limited extent, depending on their respective wavelengths. The filter *F* will also have a transmission characteristic covering a range of wavelengths. Thus there may be considerable colour mismatch between *R* and *L* unless all these factors are optimal. Nevertheless sufficient precision has been obtained for the purpose for which the monitor has been designed, despite the presence of a certain amount of mismatch.

The principle which has been described can be applied to the measurement of any ultra-violet light by appropriate choice of the luminescent material, and it is intrinsically a very cheap method. One modification, for use with lamps which produce no visible light or for *absolute* intensity measurement of the ultra-violet, rather than relative measurement by comparison with visible lines, is to use a small tungsten lamp and battery to supply the visible light with which the ultra-violet is compared. Another application is to measure the brightness of the surfaces *L* and *R* using two photocells, and after suitable weighting of the currents through the two cells, the difference is read on a meter.

It is likely that considerably greater accuracy can be obtained by this method than was necessary with the simple monitor described above. The only limitations appear to be:

(*a*) the accuracy with which the eye can match intensities, which is known to be high when the two surfaces are of the same colour;
(*b*) the extent to which colour mismatch reduces the above accuracy.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. A. Birch, of Cosmic Sales and Distribution Pty Ltd., for the loan of the lamps used in this work, and to thank Dr. A. L. G. Rees and Mr. C. Billington for helpful discussion.

REFERENCES

(1) Luckiesh, M., Taylor, A. H., and Kerr. *Gen. Elec. Rev.*, **47**, p. 7 (1944).
(2) Taylor, A. H. *Gen. Elec. Rev.*, **47**, p. 53 (1944).

A laboratory electron bombardment furnace

By P. G. England, B.Sc.,* and H. N. Jones, M.Sc.,† United Kingdom Atomic Energy Authority, Warrington, Lan

[*Paper first received* 3 *May, and in final form* 2 *October*, 1957]

A furnace is described in which small ingots (approximately 3 × ½ × ½ in.) of metal can be melted on a water-cooled copper hearth under a high vacuum (less than 10^{-4} mm of mercury). The charge is heated by bombardment with a stream of electrons emitted from a tungsten filament suspended above the charge. A d.c. potential of up to 10 kV applied between the hearth and the filament is used to accelerate the electrons. The use of such a furnace for purifying niobium and melting high purity uranium is described.

Presently known crucible materials cannot be used during the melting of the refractory metals without impairing the purity of the metal, because of the reactivity of these metals at their melting temperature. These metals are commonly melted on a water-cooled copper hearth in an arc furnace.(1) Generally, on a laboratory scale, an inert (non-consumable) electrode is used and an atmosphere of argon at a few centimetres of mercury pressure is maintained during melting. Lower pressures are avoided because the arc becomes unstable or too diffuse.

It is known(2) that variations in the residual gas pressure in the range below approximately 1 cm of mercury affect the rate of evaporation of volatile components. Therefore, the argon arc furnace is not the ideal furnace in which to carry out purification of metals. An alternative method is the use of a consumable electrode operated in a vacuum, again using a water-cooled crucible. This type of furnace suffers from the major drawback that the material can be melted only once for a short period during a given run, after which much machining must be carried out in order to re-form the electrode for a second melt.

The heating caused by the bombardment of an object by a stream of high energy electrons has been used as the basis of several types of laboratory furnace,(3,4) none of which was of the cold hearth type. Since the critical condition for the operation of electron bombardment heating is the maintenance of a low pressure (maximum approximately 10^{-4} mm of mercury), it was envisaged that a vacuum furnace could be built using a cold copper hearth and electron bombardment heating.

This paper describes such a furnace which was used to vacuum-melt small ingots (3 × ½ × ½ in.) of metal. During melting metallic impurities having an appreciable vapour pressure were removed, along with gaseous impurities which either formed volatile compounds with the metal or had a high dissociation pressure above the melt.

DESCRIPTION OF FURNACE

The unit which is described in detail below, consisted of a pumping unit on which was mounted the furnace chamber containing the copper hearth and the electron source. An adjacent power pack supplied the low voltage a.c. current used for heating the electron emitter and the high d.c. potential used to accelerate the electrons between the source and the hearth. The external dimensions of the unit were approximately 5 × 5 × 5 ft, including vacuum equipment and power supply, and the unit was therefore convenient for laboratory use.

Vacuum system and furnace body. In order to stabil the electron beam a high vacuum was necessary, and in or to maintain this vacuum, in spite of outgassing duri melting, a high pumping speed was essential. A 9 in. diffusion pump backed by a single-stage rotary pump used and this combination gave a pumping speed at baffle valve of 900 l/s down to 5×10^{-5} mm of mercu A cold cathode ionization gauge mounted on the side o furnace chamber was used to measure the gas pressure duri melting.

The furnace, shown diagrammatically in Fig. 1, fit directly on to the baffle valve (1) of the diffusion pump

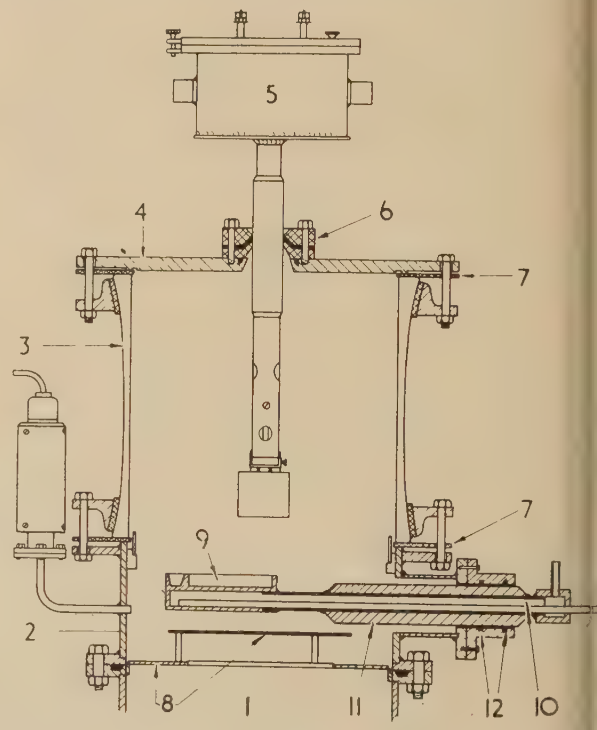

Fig. 1. Diagram of the electron bombardment furnace

consisted of a 12 in. diameter stainless steel cylinder (2) a 12 in. long, 12 in. diameter glass cylinder (3) which closed at the top by a stainless steel plate (4). The cathode was inserted through a cut-back Wilson seal (6). The gl cylinder provided insulation between anode and cathode allowed unrestricted viewing during melting. Sheet rub gaskets (7) provided seals between the steel components the furnace body and the glass; standard O-ring seals w used for the other joints.

An extra copper baffle plate (8) was included in order prevent radiation heating of the silicone vacuum oil wh ound to collect above the original baffle plate in the .

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pper hearth. The copper hearth (9) had a channel × ½ in. deep machined in it; cooling water was carried gh the concentric pipes (10) which passed into the body hearth; the thickness of the base was ¼ in. The outer pipe was brazed into a steel cylinder (11) which passed igh a double piston type O-ring seal (12) mounted on urnace body. Movement through this seal allowed the h of the hearth to be covered by a stationary electron e.

ctron source. The cathode assembly (5), which could be d through the seal (6) is shown in detail in Fig. 2. The ent consisted of a ½-in. diameter flat spiral wound from it 6 in. of 0·022 in. tungsten wire. The potential of the bdenum radiation shields could be adjusted for focusing oses, but they were mostly left at cathode potential.

e normal filament-to-hearth distance was approximately ; above this spacing the emission current obtained, for a filament current and accelerating potential, decreased. e spacing was reduced below this distance the filament rapidly contaminated by metal evaporated or ejected from harge. This contamination altered the emission charactics of the filament and, in the extreme case, portions of oil were shorted out. The cathode assembly hung from nsulated support above the furnace. Sideways displacet of the electrode through the seal allowed heating of the width of the hearth.

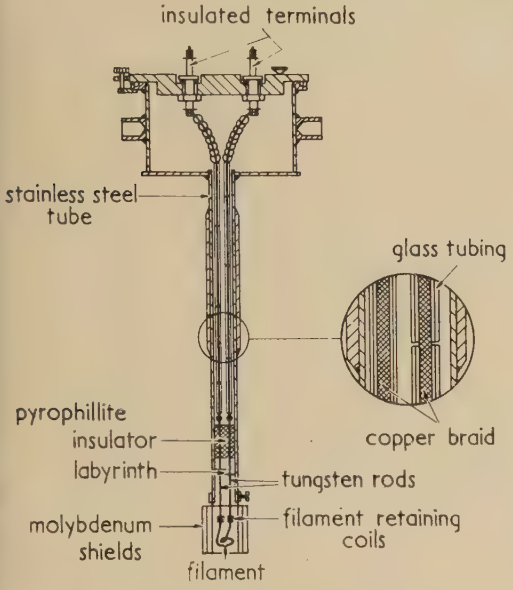

Fig. 2. Details of cathode assembly

wer unit. The power unit was a conventional mercury ur valve rectifier, capable of delivering up to 750 mA at voltages in the range 0–9·5 kV. The cathode was ed by the output from a 12 V, 20 A, winding of a high lation transformer fed from a Variac. The positive or th side of the furnace and power unit was conveniently hed in order that the hearth could be moved with the er on.

OPERATION OF THE FURNACE

order to facilitate loading of the furnace the glass nder (3) could be lifted from the steel base (2) by two cables supported on pulleys above the furnace. When the furnace had been evacuated for approximately fifteen minutes at a pressure below 10^{-4} mm of mercury the leak rate of the furnace was checked; the fully outgassed leak rate was of the order of 30 lμ/h. The filament was then outgassed by passing a current of 20 A until the pressure fell to its original value. During this operation the electrode was pointed to one side of the hearth in order to prevent heating and oxidation of the charge.

The heating cycle used for melting depended on the condition of the charge. Gassy material had to be heated slowly or else sudden outbursts of gas caused the beam current to increase uncontrollably and fuses to blow. This was due to the electron stream ionizing residual gas molecules, thus forming positive ions which bombarded the cathode. The energy given to the cathode increased the temperature of the filament leading to an electron avalanche.

The power transferred to the charge could be varied by altering the filament current and/or the cathode-anode potential. As the electrical stability of the system was greater at low potentials, this voltage was maintained at the lowest possible value, particularly in the critical stages of heating. However, fairly high potentials had to be used in order to obtain the saturation electron current for a given filament temperature. The length of the hearth was traversed at one power input and then a period was usually allowed for the glass cylinder to cool, in order to prevent excessive outgassing. The power was then increased and the ingot remelted.

As with a water-cooled, copper hearth arc furnace the part of the ingot in contact with the hearth remained solid. The ingots were therefore inverted in the hearth and remelted. If the depth of the ingot was greater than approximately ¼ in. the sides of the ingot were also melted by turning the ingot through 90° in the hearth.

TYPICAL USES OF THE FURNACE

Purification of niobium. Previous work had shown that prolonged heating of niobium at a temperature just below the melting point caused oxygen and nitrogen to be eliminated. It was believed that oxygen was lost as the volatile niobium oxide while nitrogen was eliminated as nitrogen. Using this technique of solid state purification it was possible to obtain samples with hardness figures of 45 V.P.N. (initially of the order of 120 V.P.N.), but six to eight hours treatment in the temperature range 2100–2250° C was required.

Tests were made in the electron bombardment furnace to determine whether treatment in the liquid state accelerated the removal of impurities. Small pieces of niobium (20 g) were subjected to four periods of about five minutes melting, the sample being inverted between each melting. On completion the hardness had been reduced from 120 to 40–45 V.P.N. and the oxygen content had fallen from 0·047 to 0·001%, whilst the nitrogen content had apparently risen from 0·001 to 0·004%. In order to show that nitrogen could be eliminated, a specimen was deliberately contaminated with nitrogen and then vacuum-melted for about thirty minutes. The electron beam was quite stable in spite of the relatively high pressure (4×10^{-4} mm of mercury) during much of the melting period. The nitrogen content of the metal was reduced from 1·28 to 0·43% and the oxygen content from 0·96 to 0·009%. Nitrogen and oxygen can therefore be removed from niobium by vacuum melting.

Melting of high purity uranium. The electron bombardment furnace has also been used to melt quantities of high purity uranium produced by electrolysis. The crystals of uranium were considerably oxidized and had to be pickled before melting. The ingots were remelted several times and were pickled between melts in order to remove the oxide film which settled out during melting, and which had not been removed completely by pickling. The electrolytic uranium contained appreciable quantities of lithium and potassium from the electrolyte and these were eliminated during melting.

CONCLUSION

The electron bombardment furnace described proved to be a valuable research tool which promises wide application in the metallurgy of the reactive metals, particularly where advantage is secured by the removal of volatile impurities.

ACKNOWLEDGEMENTS

Acknowledgement is made to Dr. R. F. Boyd of Universi College, London, for his helpful advice at the commenceme of the work, and also to Sir Christopher Hinton, Managi Director of the United Kingdom Atomic Energy Authori (Industrial Group), for permission to publish this paper.

REFERENCES

(1) Geach, G. A., and Sumners-Smith, D. *Metallurgia*, 4 p. 153 (1950).
(2) Spendlove, M. J. *Vacuum Metallurgy*, p. 192 (Ne York: The Electrochemical Society, 1955).
(3) Rocco, W. A., and Sears, G. W. *Rev. Sci. Instrum.*, 2 p. 1 (1956).
(4) Davis, M., Calverley, A., and Lever, R. F. *J. App Phys.*, **27**, 195 (1956).

A combined liquid nitrogen cryostat, furnace and liquid helium ba

By Miss M. J. Stubbs, and M. W. Thompson, B.Sc., Metallurgy Division, Atomic Energy Research Establishmen Harwell, Berks.

[*Paper first received* 11 *July, and in final form* 14 *August*, 1957]

An apparatus is described in which a liquid nitrogen cryostat and a furnace were associated for annealing specimens at temperatures between −196° C and 200° C. Provision was made for transferring the specimens to liquid helium without removing them from the apparatus.

During a study of irradiation damage in metals it was found necessary to measure the electrical resistance of specimens after periods of thermal annealing above their irradiation temperature. This apparatus was intended to control the temperature of a specimen at any value between −196° C and +200° C for accurately known periods of time. A liquid helium bath was provided in order to permit measurements of the residual electrical resistance between these periods of annealing.

Although the apparatus was designed for a particular experiment it is felt that some parts of it may be of general interest. The following description has been concentrated on the design and construction of a cryostat and a furnace together with their control equipment. A brief account of the liquid helium bath is included but the method used to measure electrical resistance has been described elsewhere.*

GENERAL DESCRIPTION

The diagram shows a vertical section through the apparatus. A cryostat (1) covering the temperature range −196° C to +30° C was surrounded by liquid nitrogen contained in a large vacuum flask. In order to reach higher temperatures a furnace (2) cooled by atmospheric convection, was mounted above the flask. The specimen was carried in an aluminium block (3) which was a sliding fit in either cryostat or furnace. A stainless steel tube (4) served to move the block from one section of the apparatus to another; it also provided a conduit for electrical leads and thermocouples. Below the cryostat was a double walled vacuum flask (5) containing liqu helium.

THE CRYOSTAT

Heat was supplied to a copper tube (1) $\frac{7}{8}$ in. in outsi diameter and $5\frac{1}{4}$ in. in length with 18 s.w.g. walls from electric heater winding of Nichrome tape. The turns of t winding were insulated from the tube by a layer of mica a were held in place by being woven between nine mica stri 0·275 in. wide lying along the length of the tube. The con pleted winding was coated with silicone varnish. Heat w conducted away into the surrounding liquid nitrogen by tw routes: radially, through a $\frac{1}{4}$ in. thick annular layer of paraff wax (6) enclosed by an unfired Pyrophilite casing (7) an axially, along two $\frac{7}{8}$ in. inside diameter stainless steel tub with 26 s.w.g. walls which were brazed to either end of t copper tube.

By grading the number of heater turns per unit leng along the tube it was found possible to obtain a unifor temperature over the aluminium block placed in the midd of the cryostat. The correct gradation was determined by pilot experiment in which the cryostat tube had a unifo winding over its whole length with a subsidiary winding either end. It was found that the ratio of power in the ma winding to that in the end windings which gave a unifor temperature was the same for all temperatures betwe −196° C and 30° C.

The heater was then rewound in one length with ext turns at the ends to give the power ratio determined by t pilot experiment. Using 0·003 × 0·025 in. Nichrome ta eight turns per inch were wound on the tube with elev turns over the last 0·8 in. at either end, giving a total ance of 110 Ω. The temperature of the aluminium block neasured by copper-constantan thermocouples, that of yostat tube by a similar thermocouple fastened to its oint.

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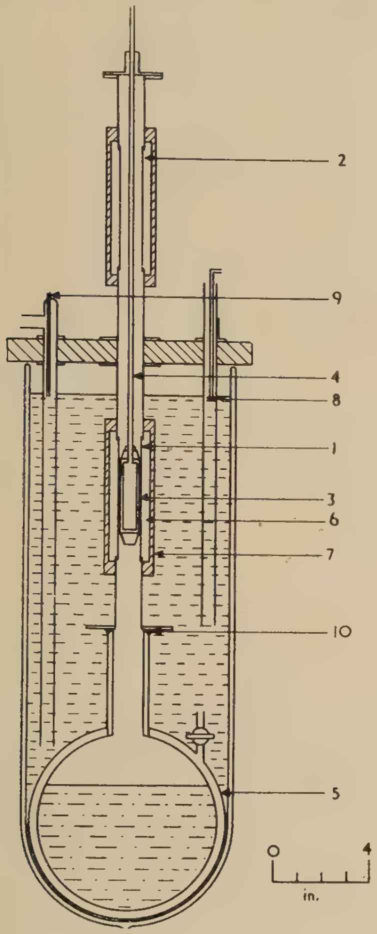
* Thompson, M. W. *J. Sci. Instrum.* (to be published).

nperature control was accomplished by comparing the at thermocouple e.m.f. with that from a Vernier tiometer (by Cambridge Instruments Ltd.), the difference fed to a galvanometer. The "spot" of this galvano- was arranged to traverse the two halves of a GS149 led double photocell connected in a circuit operating a switch. The current for the heater windings was supplied a Variac transformer and passed through two variable ances connected in parallel. In series with one of these the relay switch which, when opened, removed this ance from the circuit. With suitable adjustments to the esistances the heater current was made to change by a amount as the galvanometer "spot" moved from one of the photocell to the other. When the galvanometer ted due to a change in temperature this small change in nt was made to restore the temperature thus deflecting spot" in the opposite direction. This system of control ced a saw tooth type of temperature-time record. With a galvanometer sensitivity of 1 mm/μV a saw tooth amplitude of 1 μV was achieved. This corresponds to about 1/10° C at −196° C or 1/40° C at +200° C with a copper-constantan thermocouple. When controlling at −100° C the two values of the current were 0·86 A and 0·92 A.



Vertical section through apparatus

Cryostat; (2) furnace; (3) specimen block; (4) stainless steel e; (5) liquid helium flask; (6) paraffin wax; (7) pyrophilite ing; (8) probe resistor; (9) filling head; (10) lead washer.

An automatic filling device was fitted to the outer vacuum flask in order to maintain the level of liquid nitrogen above the cryostat assembly. A 0·1 W carbon resistor (8) carrying a current which dissipated 0·2 W formed the level probe. When the liquid level fell below this resistor its temperature rose sharply causing the resistance to fall with a consequent increase in current. A relay switch in series with the probe was made to control two electromagnetic valves. When operated, these allowed compressed nitrogen to force liquid from a reservoir into the flask through the filling head (9). This was designed to prevent bubbles of nitrogen gas from entering the liquid and causing surface oscillations. The probe resistor was mounted in an open ended glass tube which reduced the effect of surface ripples.

THE FURNACE

The design and construction of the furnace (2) was very similar to that of the cryostat. Jets of compressed air were used to cool the two stainless steel tubes emerging from the casing which was itself cooled by free convection. Paraffin wax was not used to fill the Pyrophilite casing as adequate insulation was provided by an air filled gap.

A pilot experiment was again performed in order to ascertain the correct gradation of turns in the heater winding. Using the same Nichrome tape, 8 turns/inch with 14 extra turns over the last 0·9 in. at either end gave a heater of 122 ohms.

The same temperature control system was used for the furnace as for the cryostat. At +100° C the two values of heater current were 0·32 A and 0·36 A. The highest temperature, 200° C, at which the furnace was used was determined by the specimens in the original experiment. There is no reason why the range should not be extended up to the limit set by oxidation of the furnace components.

THE LIQUID HELIUM FLASK

A double walled spherical vessel was constructed from Pyrex glass with its neck fused to a Pyrex pipeline union. A lead washer (10) was used to make a gas-tight connexion with the lower flange of the cryostat assembly. As helium gradually diffuses through the inner wall of the flask it was necessary to make provision for periodical evacuation of the insulating void. A stopcock lubricated with glycerine was therefore fitted in the outer wall of the flask.

In order to conserve helium, the tube (4) passed through a sliding seal at the top of the apparatus. To collect the gas boiling off from the flask, an outlet, not shown in the diagram, pierced the stainless steel tube below the cryostat. The gas was collected in 3 ft diameter rubber balloons prior to compression into cylinders.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. H. Montgomery for his advice on the use of liquid helium and Mrs. A. Carvell who assisted in constructing the apparatus.

Laboratory and workshop notes

A simple centrifugal circulating pump

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[*Note received* 4 *May*, 1957]

In a note recently published by Bond,* a centrifugal magnetic pump for a totally-enclosed system is described. It appears that a simplification of the construction could be achieved, if the glass (or Teflon) bearings and the dynamic balancing of the rotor magnet could be dispensed with.

As shown in Fig. 1, a glass-coated bar magnet is rotated in a simple glass envelope by a standard magnetic mixer. The inner bar magnet centres and balances itself without the need of pivots, a feature which considerably simplifies the construction of the pump. Dependent on the chemical nature of the fluid to be circulated, the pump may be built of other non-magnetic materials rather than of glass, e.g. of Perspex.

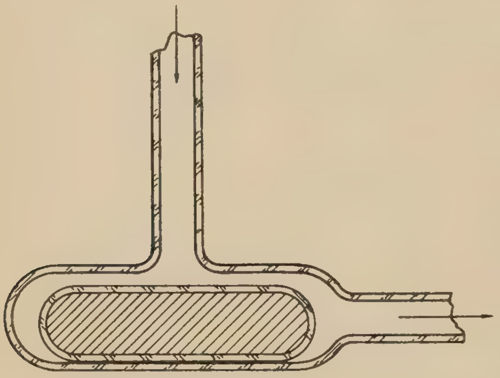

Fig. 1. Centrifugal magnetic circulating pump made of glass

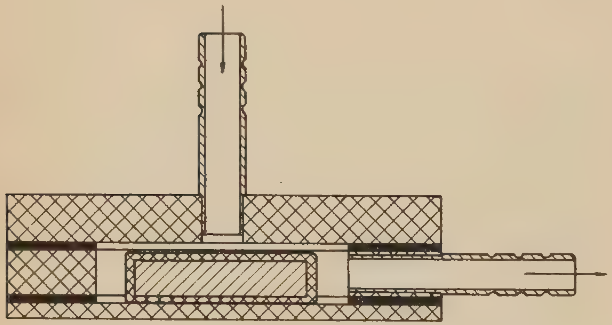

Fig. 2. Centrifugal magnetic circulating pump made of Perspex

Fig. 2 is an illustration of the proposed type of apparatus. The Perspex pump, having a rotor space of 5 cm diameter, circulates about 2 ml./s of water at 150 rev/min against a very slight resistance, or delivers a static pressure head of 10 mm of mercury.

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* Bond, F. *J. Sci. Instrum.*, **34**, p. 73 (1957).

A simple gas inlet for use with vacuum systems

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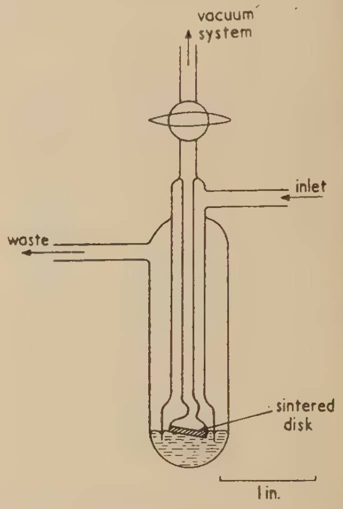
[*Note received* 8 *July*, 1957]

The transference of a gas from a cylinder or generator to evacuated system necessitates the removal of air from t connecting tubes, which is commonly effected by sweepi out through a mercury vent, and requires delicate adjustme of glass taps and constant supervision in order to preve mercury from entering the apparatus.

The gadget described obviates many inconveniences, simple, compact and trouble-free, without requiring a great precision in fabrication. The diagram is self-expla tory, and although dimensions are not critical, a sinte disk 1 cm in diameter is a convenient size.



Gas inlet for use with vacuum systems

The appliance is charged with sufficient mercury to form seal with the sintered disk (No. 4 porosity). The tap is th attached to the vacuum system, and the gas supply is attach to the inlet limb. The appliance and connecting tubes then be swept out with the gas to be used, the innermost tu being swept out by opening the tap, and the assembly is rea for use.

With the tap closed, the gas passes to waste by bubbl through the mercury. On opening the tap, gas passes throu the sintered disk and enters the system to give an ultima maximum pressure only a few millimetres greater th atmospheric, whilst any accidental fall of gas supply atmospheric pressure results in the sintered disk being seale Thus since the pressure applied must be slightly greater th atmospheric for the apparatus to function, the possibility air leaking into the connexions is minimized, and also puri ing trains comprising liquid scrubbers may be used with li fear of accident.

A greaseless vacuum seal for rotating shafts

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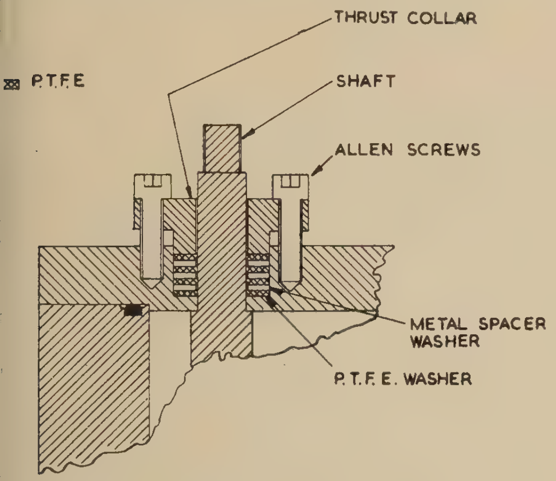
Research and Development Branch, Capenhurst Works,
Chester

A number of schemes have been devised for transmitti torque through the walls of a valve or a vacuum syste mplest way, undoubtedly, is to have a shaft running h a rubber plug in the wall of the vessel. The active of the plug and shaft are often greased with some n grade of grease, to prevent binding and to seal any : scratches in the sealing surfaces. The well-known ·packed Wilson seal is an improved version of this ement. Whilst perfectly satisfactory for many appli- s, it suffers from two serious disadvantages for work ng high vacuum standards, e.g. mass spectrometry. it is not a clean seal, in that grease can find its way ie system and the vapour can degrade the vacuum re; this is important when the pressure must be lower 0^{-6} mm of mercury. Secondly, it will not operate at mperatures because the grease melts and gives rise to this prevents high-temperature baking of tubes from carried out.

ral more complicated methods have been devised, bellows, "wobble-sticks," etc., to overcome the dis- ages of this seal, but they generally become too large imbersome to incorporate in mass spectrometers.

have therefore tried to retain the simplicity of the 1 seal and to eliminate the grease altogether. The oefficient of friction between polytetrafluoroethylene .E.) and polished steel enables us to use this material lf-lubricating packing for the gland, instead of rubber. ition, P.T.F.E. is stable up to temperatures of the order)° C, and has a very low vapour pressure, the value 3 × 10^{-5} mm of mercury at 350° C.* This enables seal to be operated well above room temperature.

construction of the seal is shown in the figure. Its icy depends on slight extrusion of the P.T.F.E. into the ir gap between the shaft and the metal washers, and igainst the wall of the recess. The arrangement of the .E. in the form of thin washers interspaced with metal rs is to give good flow conditions under a low pressure d by using a standard Allen key. The number of rs was arbitrarily chosen as four, and proved to be ictory; they were made 0·062 in. thick, with smooth for ease of machining and to impart reasonable rigidity. are a tight push fit both on the shaft and in the walls recess. The metal spacers are 0·062 in. thick, but this a critical dimension; they are highly polished, without scratches, to give the best conditions for flow of the P.T.F.E. The inside diameter is larger than the diameter of the shaft; on the prototype the clearance was 0·010 in. This ensures that the shaft does not gall on the washers, and gives room for the flow of P.T.F.E. under pressure. The P.T.F.E. and metal spacers are stacked as shown, and pressure is applied to the stack by tightening four Allen screws against the thrust collar, thus making the P.T.F.E. flow to form seals against the shaft and the wall of the recess.



A greaseless vacuum seal for rotating shafts

It can be seen that the success of the seal depends greatly on the polish finish of the shaft. There must not be any longitudinal scratches across the seals. Once the seal has been made, it should remain working in various temperature conditions without further adjustment.

Such a seal has been put into service satisfactorily at temperatures between 22 and 200° C. Tests with a helium leak detector have shown no signs of any leaks greater than 0·001 clusec, i.e. 10^{-5} lusec (1 lusec = 1 l. μ/sec).

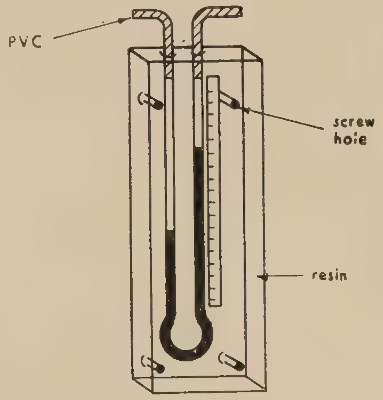
The protection of glass apparatus by embedding in transparent resin

By F. Jones, Chemical Services Department, United Kingdom Atomic Energy Authority (Industrial Group), Windscale Works, Cumberland

[*Note first received* 29 *July, and in final form* 9 *September,* 1957]

The necessity for incorporating ancillary glass apparatus into mechanical and electrical equipment inevitably decreases the overall robustness of the equipment with attendant increase in maintenance time. Whilst protective measures such as the use of clamps, Perspex panels, etc., are of value, a more permanent means of protecting glassware, particularly delicate items, is clearly desirable.

Good protection of glassware is achieved* by completely embedding in a suitable, cold setting, "water white," transparent resin known as Ceemar (by E. M. Cromwell and Co. Ltd., Bishops Stortford), which is applied in layers up to ½ in. thick around the article and within a polythene moulding box, the polymerized resin being readily detached from the mould. Where miscellaneous small glass items connected by thin fragile tubes need support, the technique is ideal, while scales for measurement, plastic tubing, Perspex, electrical



Embedded manometer

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ube Laboratory Manual, 2nd ed., p. 125 (Cambridge, Mass.: ichusetts Institute of Technology, 1956).

* U.K. Patent Application No. 15492/57.

components and metals can also be embedded. By attaching P.V.C. tubes to the glass apparatus and only allowing the ends of the P.V.C. to protrude from the plastic block, a very robust piece of equipment can be produced which can be supported by suitable rods or screw supports set into the resin.

The use of the technique for the protection of manometers (see figure), and the embedding of glass taps leaving their plugs free to turn, are typical examples of the wide range of glass apparatus which can be effectively protected.

Where liquids are handled it is an advantage to see the contents of the vessels in their natural colours and in this respect the resin named is of particular value since it is devoid of yellow coloration and its normal use is for embedding biological specimens. Further particulars are obtainable from the manufacturers' catalogue. The embedding technique ensures that should any cracks occur in the glass apparatus, the liquid is retained *in situ* and this advantage is further enhanced by the relative inertness of the resin to attack by dilute acids, a feature which is of particular value in the radiochemical laboratory where the maintenance of fully shielded apparatus is an outstanding problem.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the Managing Director of the Industrial Group of the United Kingdom Atomic Energy Authority for permission to publish this information.

A modification for use with wire resistance strain gauge circuits

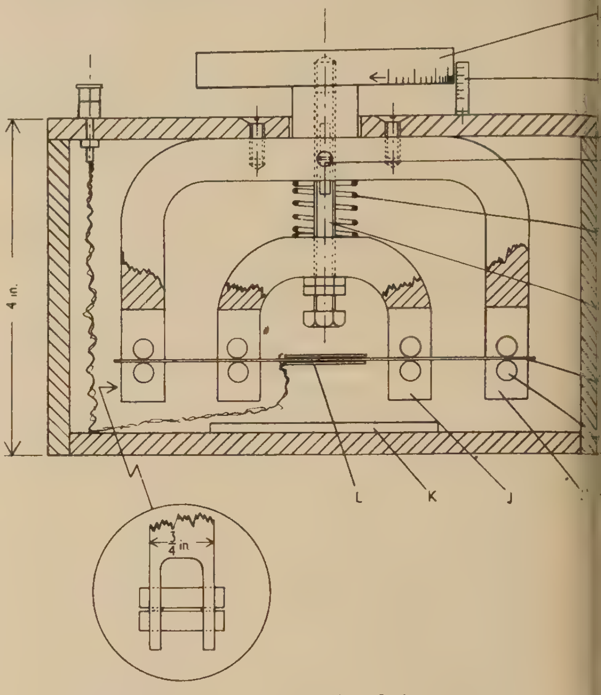
By J. Halling, Department of Mechanical Engineering, The University, Liverpool

[*Note received* 14 *August*, 1957]

In the development of an equipment for studies of friction and wear it became necessary to measure small dynamic forces. This was achieved using a standard alternating current bridge circuit in which wire resistance strain gauges were employed as the load responsive system and constituted two arms of the bridge circuit. The remainder of the bridge circuit was formed by the small piece of apparatus shown in the figure. The out of balance of the bridge circuit was displayed on an oscilloscope fitted with a moving film camera.

In the apparatus shown in the figure a light beam *F*, is constrained such that its central section is subjected to uniform bending. This beam is located by a series of rollers *G*, fitted to the two cradles *H* and *J*. A pair of identical wire resistance strain gauges *L*, are fixed above and below the central span of the beam *F*. Deflexion of the beam is caused by rotation of the control handwheel *A*. This produces a vertical motion of the screw *E*, which is prevented from rotating by the set screw *C* engaging in a slot in this screw, and thus moves the cradle *J* relative to the fixed cradle *H*. The coil spring *D* produces a resistance to motion which ensures that the system is stable at any setting of the control and also ensures a positive operation for deflexion of the beam in either direction. The degree of rotation of the control is indicated by the micrometer type scale *B*. Electrical connexions are made by wires of equal length to the terminals on the lid of the wooden box which totally encloses the apparatus.

This small and robust piece of apparatus thus replaces the standard resistances and slide wire system of the conventional bridge arrangement. It eliminates problems of co resistance and is virtually independent of temperature effe In the application for which it was designed the screw *E* 26 threads/in. and the strain gauges were identical with t used on the load measuring device. For greater sensiti the beam *F* could be designed, in conjunction with a thread on the screw *E*, to give increased rotation of the con



Section showing details of the apparatus.
Overall dimensions of box $6\frac{1}{2}\times 4\times 3\frac{1}{2}$ in.

A for the maximum permissible deflexion of the beam. maximum deflexion is limited to avoid any permanen tortion of the system. The position of the screw *E*, fixe the two locking nuts, with respect to the tapped hole in control handwheel limits the upward deflexion of the be The downward deflexion is limited by the cradle *J* contac the plate *K*. The maximum bending stress over the cen span of the beam *F* is proportional to the maximum defle of this beam. Thus the change in resistance of the st gauges is directly proportional to the rotation of the con handwheel.

It is envisaged that the simplicity and robustness of piece of apparatus may merit its application in other conte In certain instances it may prove necessary to incorpo inductance and capacitance with the gauges to obtain comp balance of the bridge circuit.

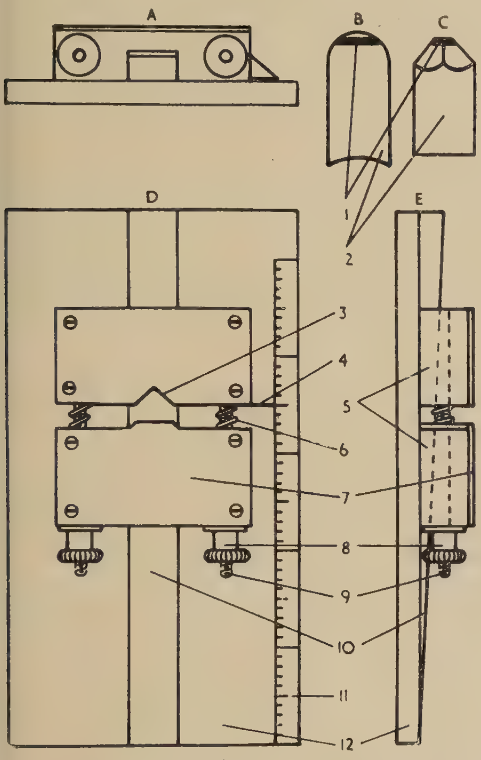
An instrument to trim specimen blocks prior to ultr microtomy

By A. L. Sims, University College, Cardiff

[*Note first received* 1 *August, and in final form* 23 *Septem* 1957]

Specimens of tissue for electron-microscopy are us embedded in a methacrylate mixture which is allowe solidify inside a gelatin capsule. Normally in recoverin specimen block from the gelatin capsule, it is found that e hemispherical (*B* in figure). The end containing e is convex and the other end, because of shrinkage, s concave.

e the tissue can be sectioned in an ultra-microtome, cessary to trim the ends of the polymerized plastic. cess plastic at the convex end is removed to leave the n the form of a truncated cone *C* containing that part tissue it is desired to photograph in the electron cope. In order to facilitate this operation it is necessary way the concave depression leaving a flat surface.



ree views of vice, and two enlarged views of a specimen block before and after trimming

Tissue; (2) specimen blocks; (3) vee grooves; (4) scale ter; (5) vice jaws; (6) compression springs; (7) metal plates; ck nuts; (9) screwed studs; (10) inclined plane; (11) scale; (12) white Perspex base.

instrument shown in the figure at *A D* and *E* takes the of a vice with sliding and locking jaws, and with it ing operations are easier to perform, because the en block is held vertically while both hands are left trim the block with a safety razor blade.

ra material for trimming is readily exposed by movement vice along the base. The amount of material exposed rmined by the position of the vice on the base, due to ear slope of the inclined plane.

Simple refractory-metal and glass-metal seals*

W. D. Jamieson, Ph.D., Atlantic Regional Laboratory,
National Research Council, Halifax, Canada

[*Note received* 12 *August*, 1957]

techniques have been described(1–3) by which glass or tory surfaces can be made electrically conductive so that they may receive an electrodeposited layer of copper or other metals. Methods based on such techniques as the chemical reduction of aqueous solutions, thermal reduction of metal hydride or other salt coatings, vacuum sputtering, friction metallizing and metal spraying are not very suitable for occasional use in the construction of laboratory apparatus. It has been found, however, that copper and other metals can be electrodeposited on a refractory or glass surface made electrically conductive by a film of graphite deposited from a dispersion of colloidal graphite in alcohol (Dag Dispersion No. 154 by Acheson Colloids Co., Port Huron, Michigan, U.S.A.), painted on the clean refractory surface and baked at about 200° C for about one hour to ensure removal of the last traces of alcohol. Adhesion of the graphite film to glass is improved if the glass surface is first made rough by grinding with carborundum. Copper is electrodeposited on the graphite-coated surface from aqueous solution (180 g $CuSO4.5H_2O$ and 25 ml. concentrated H_2SO_4 in 1000 ml.) using a copper anode, at a current density not exceeding 30 mA/cm^2. Mechanically strong gas-tight connexions to the refractory or glass are then made by soldering metal flanges or tubes to the electrodeposited copper sheath. Ordinary soft solders (60 : 40 or 50 : 50 tin–lead alloys) have been used for this purpose but there would seem to be no objection to the use of higher-melting solders if the refractory were protected from excessive thermal shock.

Metal-refractory or metal-glass seals made in this way are sufficiently gas-tight to be used in ordinary high vacuum systems. Sample seals have been found satisfactory when tested by the conventional Pirani gauge leak-testing technique.

Such seals have been used in this laboratory for over a year in the construction of various components of apparatus requiring gas-tight connexions between brass and either mullite, recrystallized alumina or glass. When laboratory furnaces are used for experiments with controlled atmospheres at high temperatures, it is necessary to effect gas-tight seals between the refractory tubing of the furnace and other components of the apparatus and it is desirable that such seals should be mechanically strong. The use of mechanically weak waxes or cements for the connexion of metals to refractories and of gaskets of rubber or similarly perishable materials can be avoided by the method described. In addition, refractory or glass tubing may be cooled efficiently by soldering a water coil of copper tubing to a sheath of copper electrodeposited on the glass or refractory in the manner described.

REFERENCES

(1) Balmer, J. R., and Heritage, R. J. *Metallurgia*, **47**, p. 171 (1953).
(2) Monack, A. J. *Glass Ind.*, **28**, p. 21 (1946).
(3) Starr, J. *Ceram. Ind.*, **55** (3), p. 78 (1950).

The preparation of spherical single crystals for X-ray diffraction work

By K. S. Revell, B.Sc., and R. W. H. Small, Ph.D., B.Sc., Department of Chemistry, The University, Birmingham

[*Note received* 28 *August*, 1957]

The manipulation of volatile crystals for X-ray diffraction work presents some practical difficulties. The usual method of dealing with such material is to prepare single crystals by sublimation and to seal one, suitably orientated, in a Lindemann glass capillary tube. Highly volatile substances such as organic fluoro compounds, however, may evaporate excessively during manipulation and an alternative method is to grow the crystal inside a Lindemann tube from the melt. The application of this method to low temperature investigations has been described.(1–3) This paper describes a modification of the technique to produce single spherical crystals of organic compounds which melt without decomposition and are not suitable for the spherical grinding procedure described by Bond.(4)

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* Issued as N.R.C. No. 4602.

The value of spherical crystals for intensity work has long been recognized in allowing the simpler calculation of absorption factors,(5) or more frequently, some justification for the neglect of absorption corrections.

The bulb for the crystal was blown from a selected piece of Lindemann capillary tube having a diameter about one-third of that of the required crystal. One end of the tube was sealed and the other passed carefully through a small gas flame so that, in one operation, the glass sealed and the expanding air within the tube blew a spherical bulb. From capillary tubing of approximately 0·2 mm external diameter, it was found possible to prepare round bulbs with an even wall thickness of about 0·002 mm, and 0·5 mm diameter. The bulb stem was opened and packed with fragments of pure crystal which were driven by the heat from a warm spatula into the bulb until the latter was slightly over full to allow for air trapped in the body of the solid; the stem was resealed about 4 mm from the bulb.

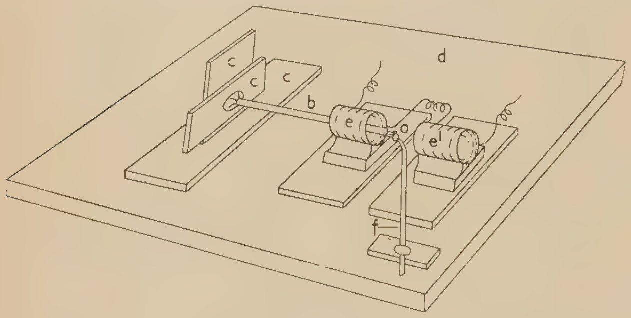


Diagram showing arrangement for preparation of crystals

A stereoscopic microscope with its axis horizontal was used for the remaining operations. The spherical bulb (*a*) was mounted by means of rod (*b*) and slides (*c*) on the glass stage plate (*d*) so that it hung vertically down and in the field of view of the microscope (see figure). The bulb stem was attached to the glass rod with cellulose acetate lacquer and the slides held in position by a thixotropic film of a para wax and oil mixture which allowed adjustment under th pressure. Two small heating coils of Nichrome wire (*e* and about 1 cm in diameter, together with a pointed length copper wire (*f*), were similarly mounted on the microsco stage. The temperature gradient required for contro crystallization was obtained by placing the copper point touching the bulb with the coils, above and below, ab 1 cm apart and coaxial with the glass rod.

With the copper point removed, the material in the b was completely melted by adjusting the heating coil curre The coils were repositioned to drive all the substance i the bulb and to allow entrapped air to escape from the m Cooling was started by gradually lowering the coil curr and with the onset of crystallization a sensitive temperat control was obtained by reintroducing the copper point. the melting temperature a single crystal mass, free f cleavage lines and bubbles, was selectively developed at expense of all others by a process of successive heating then cooling with the copper point. At this stage it was possible to control partially the crystal orientation; in presence of only one crystal nucleus at the bottom of bulb, further cooling produced a flat horizontal solid li interface which was allowed to move slowly up to the stem.

With crystallization complete at this point, cooling interrupted for a period to anneal the specimen, and continued slowly to room temperature. The unif extinction exhibited between crossed Nicols on the polar microscope and the subsequent X-ray photographs give the specimen, confirmed the presence of a single crystal.

So far this technique has been developed using Lindemann glass and pure melts. It should be possib fashion bulbs from a variety of amorphous resins and plas and also to use a temperature gradient to deposit a si crystal from a suitable liquid solvent phase.

The authors wish to thank the University of Birming for the award of an Albright and Wilson Research Stud ship to one of us (K. S. R.) and to Professor H. W. Mel for the provision of research facilities.

REFERENCES

(1) KAUFMAN, H. S., and FAUKUCHEN, I. *Rev. Sci. Instru* **20**, p. 733 (1949).

(2) ABRAHAMS, S. C., COLLINS, R. L., LIPSCOMB, W. N., REED, T. B. *Rev. Sci. Instrum.*, **21**, p. 396 (1950).

(3) POST, B., SCHWARTZ, R. S., and FAUKUCHEN, I. *R Sci. Instrum.*, **22**, p. 218 (1951).

(4) BOND, W. L. *Rev. Sci. Instrum.*, **22**, p. 344 (1951).

(5) EVANS, H. T., JR., and EKSTEIN, M. G. *Acta Cryst.* p. 540 (1952).

New instruments, materials and tools

ditor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved
ts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

ency and time-measuring equipment. Venner Elec-
ronics Ltd., Kingston By-Pass, New Malden, Surrey.

ortable apparatus is a versatile instrument incorporat-
ug-in units. It is capable of measuring any frequency in
nge 10 c/s to 50 kc/s, the period of any waveform from
/s to 100 c/s, and the time interval between two con-
ve pulses from the same or independent sources from
s to 11½ days. It can also be used to determine the open
sed time of a pair of contacts in the same time range.
l presentation is employed, the indicator for each decade
a meter calibrated from 0–9. When set to measure
ency, any of three gating times may be selected, 0·1, 1 or
The count of the unknown frequency is then carried out
e selected period. Six standard output frequencies are
ble, and any of these may be measured by pressing the
witch. An automatic timer is fitted so that repetitive
rements may be made. The display time is variable
0·5 to 5 s.

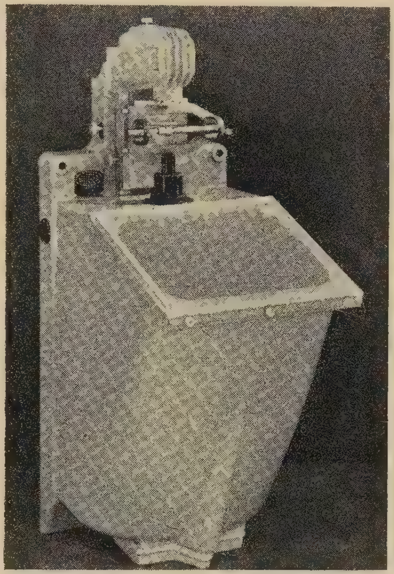
en set to measure the period of a waveform, the internal
s oscillator is counted for the duration of one input
of the unknown frequency. The display timer may be
oyed, enabling repetitive counts to be made auto-
ally. For pulse interval timing, two inputs are used.
lse fed to one of these opens an internal gate; a pulse
the other closes the gate. While the gate is open, any
e six internal frequencies can be fed to the counting
s. Thus, if the 1 c/s frequency is used, the timing is in
of 1 s; if the 1 kc/s frequency is used, the timing is in
of milliseconds. This permits a wide range of timing
carried out with optimum accuracy at all times. The
y timer may be made to operate so as to hold the
ated elapsed time for an adjustable period between 0·5 s
s, at the end of which period it resets all the decades
o in readiness for a fresh starting pulse.

e instrument employs transistors in digital circuits, both
counting and dividing stages.

kshop and inspection projector. Hilger and Watts Ltd.,
98 St. Pancras Way, Camden Road, London, N.W.1.

Chekker Projector TT708 is a small easily portable
ctor which can be used with its optical axis vertical or
ontal. Eight interchangeable lenses are provided giving
ifications of 10×, 15×, 20×, 25×, 50×, 100×, 250×,
500×. Areas viewed range from 1·0 × 0·8 in. to
× 0·015 in.

wide selection of vertical and horizontal work-stages,
or without means for measuring, is available. The work
orm supports components during their inspection. Its
are bevelled at 30° to provide location for other accessor-
nd for the customer's special fixtures. It has a plane
ce 3·6 in. wide and 5·5 in. long. Work centres holding
up to 2 in. diameter and 3½ in. in length can be attached
e work table. A single-micrometer stage can also be
lied which has a traverse of 1 in. and to which work
es can be attached. A more elaborate co-ordinate measuring stage having a traverse of 1 in. in two directions at right angles to one another is also available. Screen templates covering a wide range of standard radii, screw threads, gear teeth, etc., can be supplied from stock.



Chekker projector in vertical position, with work centres

D.C. amplifier. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

The heart of the Hilger–Negretti d.c. amplifier is essentially a sensitive galvanometer amplifier which is simple and reliable, easily maintained, and free from drift. Although aimed in the first place at industrial applications, such as thermometry by resistance-bridge or thermocouple methods, its non-electronic character and general stability of operation are said to make it ideal for a wide variety of purposes involving the measurement and recording of small d.c. voltages. It is little affected by vibration and can be used on the bench.

A single amplifier with its supply and control unit, and a double version with two measuring channels served by a common power unit, are available. Substantial input terminals are provided and the output appears at a meter jack for each channel, so that the choice of a meter or a recorder is open to the user. The unit operates from all the usual mains supplies, but it is necessary to give details of the voltage and frequency when ordering.

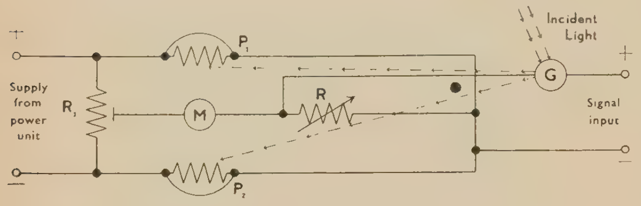
The sensitivity of the amplifier is continuously variable by means of a feedback control over a range giving 5 mA output for inputs between 5 and 50 mV. Three standard sensitivities can be set and calibrated against an internal standard cell and potential divider to give the following input-voltage ranges: 0–5 mV (e.g. for resistance bridges); 0–25 mV (e.g. for rare-metal thermocouples); 0–50 mV (e.g. for base-metal thermocouples).

Other sensitivity calibrations can be effected to meet customers' requirements. A centre-zero meter will allow inputs of opposite sign to be measured.

The input impedance varies with the degree of feedback and is of the order of 20 000 Ω for the 50 mV sensitivity. The response time for the same sensitivity is about 1 s.

Mains voltage changes of ±10% can be tolerated.

The diagram gives a schematic circuit of the amplifier.



Schematic circuit diagram

The mirror of a galvanometer *G* reflects a beam of light from a filament lamp to a split photocell P_1P_2. The bridge circuit $R_1P_1P_2$ is arranged to be balanced for "zero" input to the galvanometer, and meter *M*, connected in the circuit externally, indicates zero. Any small deflexion of the galvanometer by an input signal causes the illumination of one-half of the split photocell to be increased at the expense of the other. The bridge then becomes unbalanced and a resultant current flows through meter *M*. Negative feedback, controlling the sensitivity and stability, the speed and the linearity of response, is derived across the feedback resistor *R*, which is connected so that the output current tends to oppose the input current through the galvanometer.

The system depends inherently on the sensitivity of the photocell to differential changes of illumination of its two halves. The large current gain obtainable in this way through a "galvanometer relay" enables feedback to be introduced to stabilize the response and to make it less dependent on the individual parameters of the system. Cold-junction compensation networks for thermocouples can be fitted in series with the input connexions.

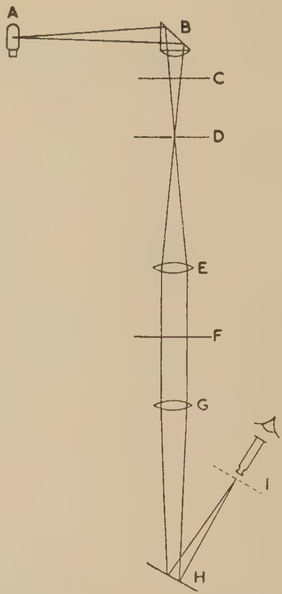
The need of some users for remote checking and metering can be met. The power unit may be equipped with relays which enable the action of checking the zero and calibration to be carried out at a remote station, as well as providing for the installation of an indicating meter. All the connexions for such a remote control point are made *via* a multiway socket at the rear of the power unit. There are two such sockets for control of the double system.

Optical diffractometer. R. B. Pullin and Co. Ltd., Phoenix Works, Great West Road, Brentford, Middlesex.

The purpose of the optical diffractometer is the observation and study of diffraction effects. A most important use of the instrument is to assist in the solution of X-ray diffraction problems(1–3) and in the field of radio astronomy. A further use is the demonstration of experiments in physical optics to students.

The principle of the diffractometer is shown in the diagram. Light from a 250 W compact-source mercury vapour lamp *A* is directed by means of a prism and lens *B* through a monochromatic light filter *C* on to a pinhole *D* which is at the focus of the lens *E*. The parallel beam so produced is brou to a focus in the plane *I* by means of the lens *G* after reflex at the mirror *H*. A mask *F* produces diffracted beams wh form images in the plane *I* which may be observed by aid of a microscope.

This firm also markets a pantograph punch which facilita the production of the masks which represent either the ato



Principle of optical diffractometer

arrangement or other system whose optical transform desired. The pantograph has a reduction ratio of 12 : that masks on a suitable scale (2 cm = 1 Å) can be ma from drawings up to 2 ft square. The punch mechanism foot operated and can punch holes of several differ diameters.

REFERENCES

(1) Hughes, W., and Taylor, C. A. *J. Sci. Instrum.*, p. 105 (1953).
(2) Taylor, C. A., Hanson, A. W., and Lipson, H. *Pr Roy. Soc.*, **218**, p. 371 (1953).
(3) Hanson, A. W., and Menarry, A. *J. Sci. Instru* **33**, p. 24 (1956).

True r.m.s. voltmeter. Consolidated Electrodynamics C poration, 300 North Sierra Madre Villa, Pasade California, U.S.A.

The model 14 A r.m.s. voltmeter is particularly designed making noise-level measurements on apparatus operating audio or radio frequencies. It consists of a thermo-mi ammeter fed from a mains operated transistor ampli with a co-axial input attenuator. The instrument measu voltages from 0·5 mV to 200 V in the frequency range 15 to 0·5 Mc/s with an accuracy of about 0·5%. The use transistors eliminates the warming-up period needed w thermionic devices, and the makers claim that the instrum attains its normal accuracy 30 s after switching on. By t use of transistors, printed circuit wiring and miniature co ponents, the size of the instrument has been reduced 6 × 6 × 8 in. and the weight to 7½ lb.

sal bridge. Marconi Instruments Ltd., St. Albans, ertfordshire.

F 868A universal bridge is a development of the Com- earlier TF 868/1 instrument. It incorporates a bridge monitoring system. For inductance or capacitance rements, the bridge is energized by an a.c. voltage d from a valve oscillator. This voltage can be set to esired value in the range 0–10 V. This facility is ally useful when measurements are being made on nents such as iron-cored coils whose inductance is a on of exciting current. The bridge measures inductance from 1 μH to 100 H, capacitance values from 1 pF to and resistance values from 0·1 Ω to 10 MΩ. Induc- or capacitance measurements can be made at frequencies er 1 or 10 kc/s; resistance measurements are made with In all cases, bridge balance is indicated by a moving-coil

m tube voltmeter. Marconi Instruments Ltd., St. lbans, Hertfordshire.

ew type TF 1041A vacuum tube voltmeter measures a.c. .c. voltage and d.c. resistance. The frequency range . measurement extends from 20 c/s to 1000 Mc/s. The capacitance is 1·5 pF; input resistance is 0·5 MΩ at c/s and 150 kΩ at 100 Mc/s. The voltage range is 0·05 0 V. D.C. measurements can be made of balanced or lanced potentials up to 1000 V at an input impedance MΩ balanced or 20 MΩ unbalanced. Used as an neter, the instrument measures resistance from 0·2 Ω 0 MΩ.

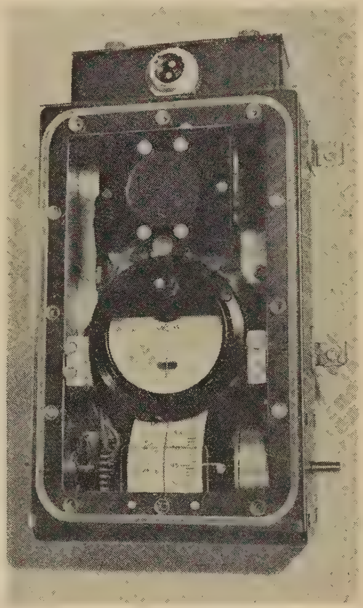
Vacuum tube voltmeter

r measuring a.c. potentials, there is a specially designed to make point contact with the source under test. The cylindrical probe unit (weighing only 1½ oz) houses a seal diode rectifier having a resonant frequency of Mc/s, low interelectrode capacitance and short transit A special ground connector is supplied for use with robe unit, so as to make the ultra-short connexions sary at the higher frequencies. The d.c. section of the is essentially a two-stage impedance converter. Each stage includes two cathode followers, and there is heavy negative feedback between the input points and the moving-coil meter across the output. For d.c. potential measurements there is a meter-reversing switch and a three-lead rubber moulding which can be fitted with either prods or crocodile clips. A feature of the instrument is the large meter with anti-parallax mirror and long scale.

Three accessories still further increase the range of the instrument. D.C. voltages up to 30 kV can be measured using the type TM 5033 multiplier unit; the a.c. measurement range can be extended to 2 kV using the type TM 5032 multiplier; for measuring potentials on coaxial lines, there is available a plug-on T-connector for attachment to the diode probe.

Photoelectric ohmmeter. Fairey Aviation Co. Ltd., Weapon Division, Heston Aerodrome, Middlesex.

This instrument has been specially designed for testing firing circuits. For this purpose, the current and voltage in the test circuit must be strictly limited under all conditions of failure both of the instrument itself and of the circuit under test. In the present instrument, this has been achieved by using as a source of power for the Wheatstone bridge circuit a selenium photocell. This is so made that its output under all conditions of illumination is less than 0·7 V on open circuit or 10 mA on short-circuit. The bridge circuit itself consists of wire-wound resistors cast in an Araldite block for the ratio arms and a cam-corrected rheostat for the variable element. The instrument covers the range 0–10 kΩ in four ranges. The bridge circuit itself is capable of an accuracy of 0·3%, but in order that the built-in galvanometer may respond to a change in the variable element as small as this, it is necessary that the photocell be energized with high intensity illumination. For lower intensities of illumination (of the order of 10 foot-candles) the measurement accuracy is of the order of 5%.



Chassis of photoelectric ohmmeter removed from case

New books

Magnetic amplifier circuits. By WILLIAM A. GEYGER. 2nd Edition. (New York: McGraw-Hill Book Company, Inc.; London: McGraw-Hill Publishing Co. Ltd., 1957.) Pp. 394. Price 52*s.* 6*d.*

This book is a very practical description of a very large number of methods of connecting up transductors and using them for a large number of different purposes. Undoubtedly, the most valuable parts of the book are the bibliographies which are placed at the end of each chapter and which are remarkably complete. It is useful that the book includes magnetometers and flux-gates using saturating magnetic cores and the second harmonic-type circuits are dealt with.

Unfortunately, the book mostly contains results quoted from other published works and the theory of operation of magnetic amplifiers is not derived. Similarly, the formulae for calculating transient response are quoted but are not derived. It is evident that the inherent negative feedback of the simple magnetic amplifier circuit has not been recognized and no mention is made of the effect of reactive loads on the behaviour of magnetic amplifiers.

The book gives a remarkably comprehensive picture of the history of the development of magnetic amplifiers and the first edition was one of the first comprehensive books on the subject. It is a great pity that the second edition does not include an orderly presentation of the theory underlying the behaviour and operation of magnetic amplifiers such as may be found in some of the more recent publications.

J. F. COALES

Tubes for computers. (Eindhoven: Philip's Technical Library; London: Cleaver-Hume Press, 1957.) Pp. ix + 51. Price 9*s.* 6*d.*

This little book, which has been compiled by members of the electron tube division of the Philip's organization, will be useful to all physicists and engineers concerned with the design of counting and computing circuits. The "tubes" considered are exclusively those produced by the Philips–Mullard organizations and include types E90CC, E92CC, E88CC and E91H as well as certain cold-cathode discharge devices. An introductory section explains the action of binary counters, multivibrators, and gates, and circuit details are given in the text. There are numerous errors and obscurities, for example the statement, on page 5 (1), about pulse sensitivity of counters; the value of heater current on page 17 given in volts; and the inter-electrode capacities on the latter page and elsewhere. There are also numerous spelling errors.

A. D. BOOTH

Transistor circuit engineering. Edited by RICHARD F. SHEA. (New York: John Wiley and Sons Inc.; London: Chapman and Hall, 1957.) Pp. xx + 468. Price £4 16*s.*

"First catch your hare," said Mrs. Beaton, but the physicist, having caught his transistor, may still have difficulty with the plethora of recipe books. In such circumstances the present volume can be recommended.

Author or editor of several books on transistors, R. F. Shea is well known in the field of transistor circuit engineering, and this latest book, compiled from the writings of eight of his colleagues at the American General Electric, may be ta as authoritative.

Essentially an engineering text, the book, beginning w the data sheet which the manufacturer supplies with transistor, deals with the design of circuits for a wide ra of applications. The linear equations of circuit analysis elegantly presented in matrix form; each chapter has bibliography; and there are many numerical examples. T early chapters on basic considerations are the most valua part of the book, and will be useful to physicists consideri whether transistors can aid their research programm However, whether buying old cars or transistors: *cav emptor.* The reader should remind himself of this bef reading those portions of the book which cover the use transistors in such things as domestic broadcast equipme where neither the price nor the performance of transis yet compare with thermionic valves, and the special propert of these fascinating semiconductor devices are not always advantage. This is particularly true of the high freque applications of transistors and perhaps accounts for t vagueness of some circuit diagrams, devoid of even nomi indications of the magnitude of the circuit elements. H ever, all-in-all, the authors have written a competent well-named text book.

G. B. TOWNSEND

Notes on applied science No. 15: Application of spring s to instrument design. (London: H.M. Stationery Off 1956.) Pp. iv + 25. Price 2*s.*

The application of elastic movement to physical appara has developed considerably in the last ten years. An elas comb has been proposed, for example, by Strong for averagi the straightness of several parallel ways and thus improvi rectilinearity of movement in a diffraction grating ru engine. A similar principle of elastic averaging of thousa of constraints is embodied in the Merton nut to overco periodic errors in a screw. In a different field, the "tuni fork" gyroscope is an example where the elastic hinge h appeared as an alternative to the normal rotary bearing.

Besides these new applications, there have been develo ments in the use of spring strips for translation and rotati movements in scientific instruments; in this field the staff the National Physical Laboratory, starting with the pioneeri work of the late Mr. E. M. Eden, has made valuable cont butions. We therefore welcome the appearance of *Notes applied science No.* 15 which summarizes the experience N.P.L. and other workers, and thus provides a helpful—a inexpensive—addition to the relatively small amount literature on the subject. The N.P.L.'s intention is "to gi the designer a working knowledge of the subject whi should enable him to make good use of spring strips to so suitable problems of design with which he may be confronte This intention is well fulfilled. A useful short list of referenc is provided, including one to the fuller bibliography recen published by the British Scientific Industries Resear Organization. With their low price, the Notes can be war recommended to all instrument workshops and to all stude and research workers who may encounter instrume problems.

R. V. JONES

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

tronic equipment. A. E. Cawkell, 6–8 Victory Arcade, ll, Middlesex. An 8-page illustrated catalogue gives of a range of electronic equipment divided into the ing categories: Sound, noise and vibration measure- non-destructive testing; pulse/time techniques and rement; servoscope (very low frequency oscilloscope); neutralizer; stabilized power supply tester; 1 kW and oscillator-amplifier; 400 c/s 3 phase power supply; n-built equipment.

dle valves. W.S.A. Engineering Co. Ltd., 5–9 Hatton London, E.C.1. A leaflet describes needle valves, extra fine adjustment to needle, which are claimed to recision adjustment and close regulation of flow in pipes.

h vacuum pumps. Edwards High Vacuum Ltd., Manor , Crawley, Sussex. A 24-page illustrated catalogue full details of "Speedivac" rotary high vacuum pumps er with information on all accessories which are available "Speedivac" range including magnetic valves, vacuum nsers, moisture traps and manifolds and non-return alves.

emeter recorder. Bailey Meters and Controls Ltd., Way, Croydon, Surrey. Leaflet E11–13 describes a hart telemeter recorder which operates in conjunction n electrical transmitter to provide a permanent record iables such as flow, level, pressure, machine operations noke density.

ter. Doran Instrument Co. Ltd., Stroud, Gloucester. t No. 105S gives details of a small, compact and self-ined pH meter of the potentiometric type requiring no l skill to operate but capable of giving sufficient accuracy neral laboratory use.

orite polychromator. Hilger & Watts Ltd., 98 St. as Way, Camden Road, London, N.W.1. A 4-page ated leaflet CH 400 describes a new fluorite poly-nator which, it is claimed, can automatically analyse n, phosphorus or sulphur in steel in a period which d not exceed two or three minutes.

ble capacitance monitor. Addison Electric Co., Ltd., Bosworth Road, London, N.W.10. A leaflet describes eries K capacitance gauging systems which have been ned to monitor continuously, and maintain constant natically, the capacitance of insulated conductors. Their application is to the control of wall thickness of cellular amed plastics, and that of telephone and high frequency s whose specifications call for constant capacitance r than constant diameter.

ta processing system. Beckman Instruments Incor-ted, Anaheim, California, U.S.A. A new 8-page brochure ibes the model 112 data processing system which is ed to provide an accuracy of $\pm 0{\cdot}01\%$. It is said to d the capabilities of many present-day transducers, but provide the accuracy necessary to give information for num plant operation.

ectrochemical analysis. Hilger & Watts Ltd., 98 St. ras Way, Camden Road, London, N.W.1. Five new ogues describe a complete range of apparatus for sion spectrochemical analysis. Space is given to several new or recent instruments as well as to older and now standard items of equipment. The catalogues are numbered CH. 401 to CH. 405.

Force-on-a-conductor balance. Griffin and George Ltd., Ealing Road, Alperton, Wembley. An illustrated leaflet (P2024) describes a new self-contained balance for use in the direct measurement of the force on a conductor carrying a current in a magnetic field. The maximum force measurable with the apparatus, 1 g weight, corresponds to a current of approximately 2·5 A, which is readily measured by ordinary laboratory equipment.

Laboratory furniture and apparatus. Griffin and George Ltd., Ealing Road, Alperton, Wembley, Middlesex. Catalogue P2029 illustrates a wide range of laboratory furniture in both wood and metal. Illustrations of some recent installations are followed by general hints on planning a modern laboratory. The publication concludes with a wide range of ancillary equipment including sinks, taps and multi-service units. The catalogue comprises the first section of the recently issued catalogue (56S) of chemical laboratory apparatus.

Standard cells. Doran Instrument Co. Ltd., Stroud, Gloucester. Leaflet 111 gives details of the "Weston" normal cadmium cell which has been adopted as a standard cell for precision electrical measurements owing to its long term stability and low temperature co-efficient. The leaflet also gives details of a similar cell which is of very much smaller volume.

High temperature cements. Morgan Crucible Co. Ltd., Battersea Church Road, Battersea, London, S.W.11. A 7-page booklet gives information on Brimor high temperature cements which were originally developed for securing wire strain gauges to components prior to high temperature tests. The cements have other properties which are: good bonding to metals and ceramics; good mechanical strength; good resistance to thermal shock and good electrical insulation. All these properties are claimed to be retained at temperatures up to about 750° C.

Thread illuminator. Meiners Optical Devices Ltd., 121 London Wall, London, E.C.2. A leaflet gives details of the Loom-Lite thread illuminator. This precision optical lighting unit, attached to the loom, gives a concentrated horizontal beam of light parallel to the face of the cloth, between the breast beam and the fell. A mirror, angled at 45°, reflects the beam direct to the reed and, through the reed, into the heddles thus enabling the immediate detection of any faults in the thread.

Potentiometric instruments. George Kent Ltd., Luton, Bedfordshire. Publication 351 gives details of "Commander" electronic potentiometric instruments.

Blood cell counter. Evans Electroselenium Ltd., Harlow, Essex. Leaflet F131 gives details of a blood cell counter which provides a rapid means of obtaining blood cell counts with an accuracy better than $\pm 3\%$, superseding the visual/microscope count and enabling over thirty determinations to be made in one hour. The counter provides white as well as red cell counts and needs as little as $0{\cdot}02$ ml. of blood as a sample.

Notes and comments

New literature on atomic industry

The Atomic Industrial Forum has announced the availability of papers from sessions of its recent conference on "The 1957 nuclear industry." The papers cover 20 primary areas in nuclear development.

The subject areas for which sets of papers are available include: research and test reactor progress, uranium production, radiation applications, appraisal of the atomic industry, U.S. power reactor experience, reactor fuel reprocessing, instrumentation responsibilities, financing, U.S. power reactor programme in review, reactor fuel manufacture and handling, progress in nuclear standardization, legal problems, atomic activities outside the United States, reactor components and accessories manufacture, economic incentives in the nuclear industry, information and training, factors affecting power reactor construction, marketing, financial protection against nuclear liability and advanced reactor concepts. An average of five individual papers are listed under each subject area.

A complete conference paper catalogue is available from the offices of the Atomic Industrial Forum, 3 East 54th Street, New York, U.S.A.

Survey of iron and steel research developments

As in previous years, the 1957 issue of the *BISRA Survey* concentrates on news of research projects which have reached an interesting stage of development. The contents reflect the current interest in process control and automation and the work of the British Iron and Steel Research Association's Development Section in assisting industry to adopt the results of research is especially featured. Copies are obtainable from the Association, 11 Park Lane, London, W.1.

Molecular physics

We have received the first issue of a new quarterly periodical entitled *Molecular physics*, edited by Professor H. C. Longuet-Higgins of Cambridge, and published by Taylor and Francis Limited. The group of scientists from different countries, to whom the journal owes its establishment, felt the need for bringing together papers on the physics of molecules which might otherwise be missed. The new journal will deal particularly with: (1) molecular structure and dynamics, (2) the electric and magnetic properties of molecules, and the processes of molecular excitation, ionization and dissociation, and (3) the equilibrium, transport and relaxation properties of molecular assemblies.

The price of the annual volume is £4 15*s*. ($13.30) including postage, and single parts £1 5*s*. ($3.50) plus postage. Orders should be sent to the publishers, but those originating U.S.A. and Canada should be sent to the Academic Pr Inc., 111 Fifth Avenue, New York 3, N.Y., U.S.A.

We wish the latest of the many additions to our c temporaries all success.

The Physical Society's annual exhibition of scientific inst ments and apparatus

The Physical Society announces that its forty-second ann exhibition will be held at the Royal Horticultural Societ Old and New Halls, Westminster, London, S.W.1, fr 24–27 March, 1958 (inclusive).

Entrance to the exhibition is by ticket only and these a be obtained, free of charge, from the offices of the Soc 1 Lowther Gardens, Prince Consort Road, London, S.W Members of The Institute of Physics may obtain tickets f the Institute's office. The handbook of scientific instrume and apparatus published in connexion with the exhibitio available from the Society, price 6*s*.; by post 7*s*. 8*d*.

Erratum

On page 404 of the October 1957 issue of this Journal th appeared two errors in the paper by N. R. Hansen. column 1, line 10, "left" should read "right." In colum line 4, "left" should read "right."

British Journal of Applied Physics

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An improved spray droplet technique for quantitative electron microscopy, H. L. Nixon and H. L. Fisher.

A property of a buckled elastic rod. By G. A. V. Leaf.

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The sampling efficiency of the thermal precipitator. By H. H. Watson.

New books

Notes and comments

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The Venturi pneumatic pyrometer

By A. M. Godridge, M.Sc., A.Inst.P., R. Jackson, M.Sc., Ph.D., F.I.M., A.M.I.E.E., F.Inst.P.,
and G. G. Thurlow, M.Sc., A.M.Inst.F., A.M.I.Mech.E., The British Coal Utilization Research Association,
Leatherhead, Surrey

[*Paper received* 16 *August*, 1957]

An instrument for measuring gas and flame temperatures, is described. From design considerations it is shown that the instrument can be used at higher temperatures than existing probe instruments and has a very rapid rate of response. The operation of the instrument is discussed and examples of its use are given. In the downtakes of open-hearth furnaces and in water-tube boilers the instrument shows advantages over the suction pyrometer in speed of response and freedom from blockage. Results have also been obtained at temperatures higher than those at which any other method of obtaining local temperatures has proved successful.

1. INTRODUCTION

principle of determining the temperature of a gas from a urement of its density is far from new. In a static ngement, it provides the basis of the gas thermometer, st the dynamic form, the "pneumatic pyrometer," has developed by various workers such as Moore,[1] Black- r,[2] Wildhack[3] and the present authors.[4] In these uments a sample of the gas under examination is drawn ugh a first restriction, is cooled, and then passed ugh a second restriction at which its temperature is sured. The temperature of the hot gas is calculated the pressure drops through the two restrictions and temperature at the second, cold, restriction.

evious instruments of this type used orifice plates as the rictions. Tests at this Laboratory have shown[4] that, n used on furnace gases, these instruments can be used to very high temperatures—an upper limit has not yet encountered—and also give a high rate of response. iculty was experienced, however, due to deposition on the ces, while overheating of the orifice plates at high tem- tures led to problems of damage and inaccuracies due to ansion and distortion. It was also found necessary to use irly long entry section before the first orifice to ensure the pressure drop was not affected by the aerodynamic ditions outside the probe. This resulted in error due to ling of the gas before the first pressure tapping.

ne proposed solution[5] was to replace the orifice plates rear-facing Pitot tubes but, while this solved some of the blems due to deposition, difficulties due to cooling and low pressure differentials were experienced.

second solution which avoids many of these difficulties been developed and forms the subject-matter of this paper. his modification, the orifice plates are replaced by Venturi ions, giving the "Venturi pneumatic" pyrometer.

asic theory (see comments in Appendix I). The pressure p, Δp, across a constriction in a flow of gas is related to mass flow M, and the density of the gas ρ by the equation a non-compressible gas:

$$\Delta p = kM^2/\rho \tag{1}$$

re k is the Venturi coefficient.

y the "ideal gas law"

$$\rho = mP/RT \tag{2}$$

re m is the molecular weight of the gas, P is the gas pressure, R is the universal gas constant, and T is the absolute gas temperature.

In the pneumatic pyrometer, two constrictions are installed in series. If we designate the one at the entry as 1, and that at the exit as 2, then, if the mass flows are equal at the two constrictions, we may, from equations (1) and (2), put

$$\frac{\Delta p_1 P_1 m_1}{k_1 R T_1} = \frac{\Delta p_2 P_2 m_2}{k_2 R T_2} \tag{3}$$

The pressure drop down the probe between the two constrictions is small enough under the conditions used to be neglected, and hence we may put $P_1 = P_2$. The molecular weight of the gas may change owing to reassociation of dissociated gases between the constrictions or to chemical reaction, but it is shown in Appendix I that, under normal conditions in industrial furnaces, such changes are small, and it is justified to put $m_1 = m_2$. Even in cases where this assumption is not justified, it is possible to calculate and apply a correction factor if the gas leaving the probe is analysed.

Hence $$T_1 = K(\Delta p_1/\Delta p_2)T_2 \tag{4}$$

where K is a constant for the instrument, termed the "instrument coefficient."

2. THE INSTRUMENT

Fig. 1 illustrates one form of the instrument designed for use in industrial furnaces.

The probe. The water-cooled probe has an internal bore of about 1 in. The outside dimension depends on the amount of cooling required. In the design shown in Fig. 1 it is 3 in. diameter. The length of the probe is chosen in relation to the thickness of flame or gas to be examined and the available floor space at the back of the point of entry. A shaped nose-piece incorporating the hot Venturi section A fits on the end of the probe. A plain (uncooled) tube B, is a sliding fit into the opposite end of the water-cooled tube and carries the second "cold" Venturi C.

The design of the hot Venturi is shown in more detail in the exploded view (Fig. 1 inset). The end of the water-cooled probe contains a recess D as shown, provision being made to ensure that the cooling water circulates round the lip. The hot Venturi unit, which should be built of a corrosion resistant steel to suit the particular range of furnace gases in which the instrument is to be used, slides into this recess. It is designed so that the annuli behind both sets of pressure tappings can

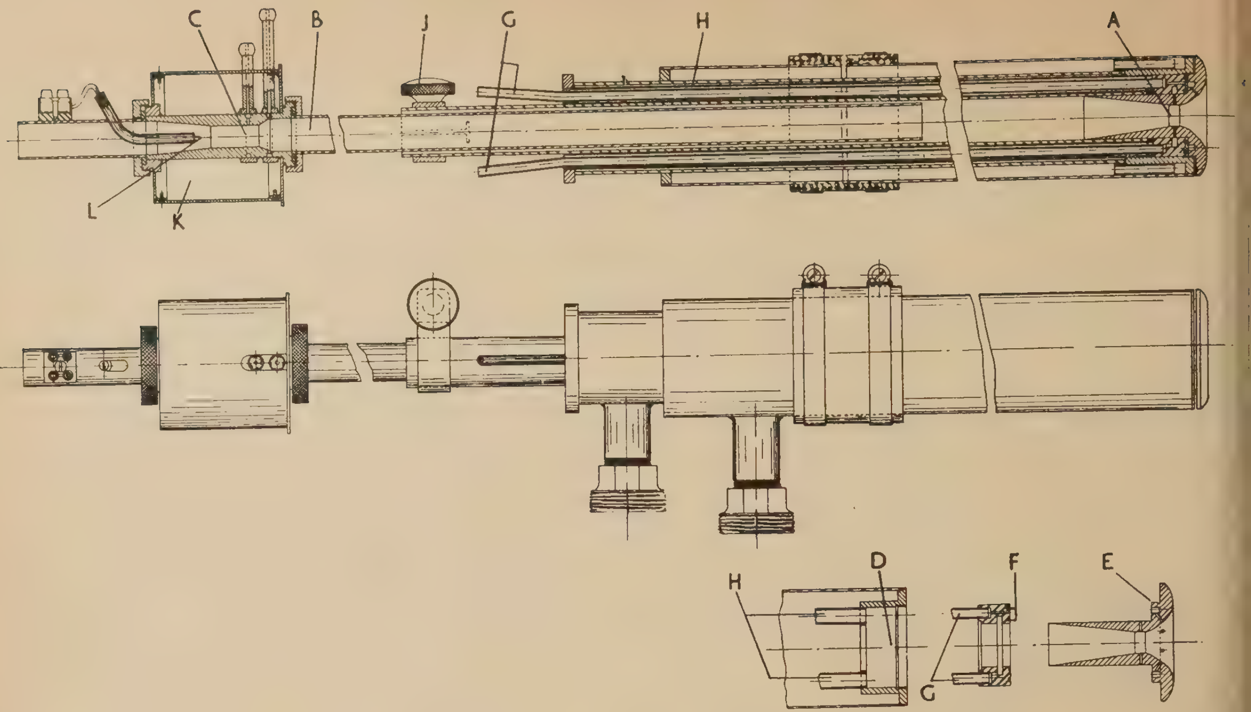


Fig. 1. The Venturi pneumatic pyrometer (Mk. II)
Inset. Exploded view of hot Venturi (sealing rings not shown).

be opened up and cleaned. The two halves are held together by the outer section screwing down on to the water-cooled jacket at *E*, leaks between the two pressure tubes and atmosphere being prevented by the sealing rings at *F*. The instrument can be taken to pieces without leakage of water into the pressure lines, as the tubes *G* from the two pressure tappings pass through the water-cooling of the probe by the two longitudinal passages *H*. The entry nozzle was designed in accordance with the considerations which are discussed in Section 3.

The aspirated gases pass through the hot Venturi, the water-cooled bore of the probe, the plain tube which projects into this and the cold Venturi. The distance of insertion of the plain tube can be adjusted by the clamp *J*, care being taken to avoid air leakage. The cold Venturi *C*, is surrounded by a case *K*, containing low temperature insulation. A single chromel–alumel thermocouple *L* is installed as shown.

Direct indicating unit. Direct reading of gas temperature from the two pressure drops and the cold-end temperature is desirable. The problem could be approached by controlling the flow rate, but the alternative approach, by solving the equation relating gas temperature to the three measured quantities in a simple computer system, has been used by the authors. The unit, developed by Evershed and Vignoles Ltd. and illustrated diagrammatically in Fig. 2 is described in detail in Appendix II.

The computer incorporates visual indication of the pressure drops, cold end temperature and the input currents. The final output is given both by a visual indicator and a separate electronic recorder.

Auxiliary equipment. The only other auxiliary equipment needed with the pyrometer is a small suction fan (maximum flow rate about 10 ft^3/min against 10 in. water gauge pressure) with some means of adjusting the flow, together with suction lines, pressure lines and water hosing.

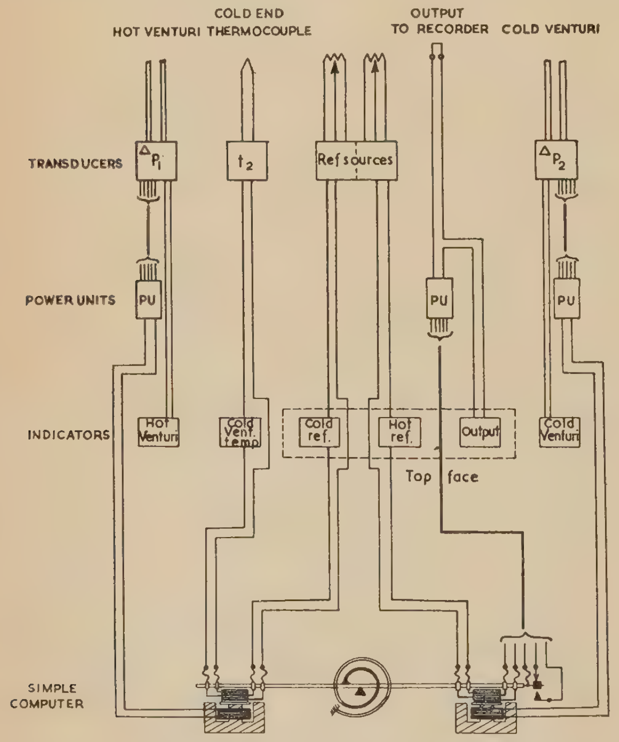


Fig. 2. Diagram of direct indicating unit for Venturi pneumatic pyrometer

3. DESIGN CONSIDERATIONS

The hot Venturi. The design of the hot Venturi shown in Fig. 1 has been evolved from various preliminary designs and experiments. Whilst the design of the entry nozzle does onform to any specific Venturi standard, it is thought a reasonable compromise between designs giving a temperature drop before the pressure tappings and in which the velocity head of the gas in the main stream s the pressure at the outer tapping.

direct measurement of the amount of cooling taking before the gases pass the pressing tappings is available, o observation has been made or inconsistency in the s has been found so far that would indicate any icant error due to this cause.

an early design of probe,(6) in which the outer pressure ng consisted of an annular slot with one tapping leading it, significant errors were caused by the velocity of the stream past the end of the probe. Hence the later n, shown in Fig. 1, incorporates a ring of six holes at the outer pressure point and the Venturi throat to nize this effect. An investigation has been carried out is design using a full-scale Perspex model of the head in h the pressure at each hole was recorded separately. 3 shows the model being tested, attached directly to the al rear section of the actual instrument.

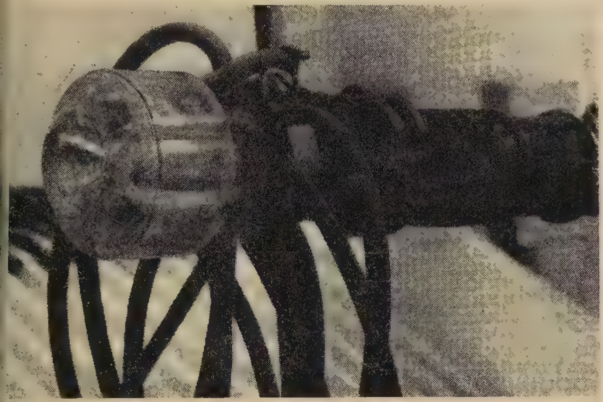


Fig. 3. Model for testing influence of cross flow

was confirmed initially that no significant variation in sure occurred round the rings when sucking from still The head was then subjected to flows of air, (i) parallel nd directly into the Venturi entrance, (ii) at right angles he head, and (iii) midway between these two extremes. se flows were produced by locating the head in the centre of a free jet of large cross-section from a centrifugal ver, the variation in velocity of the jet with distance having n previously determined by Pitot traverses. Tests were ied out with the blower nozzle at three distances from the lel head giving free stream velocities of 25, 50 and 75 ft/s. ee flow rates through the probe were examined in each , equivalent to pressure differentials at the cold Venturi , 2 and the normal operating condition of 3 in. water ge. The flow rates at these conditions were approximately and 7 ft^3/min respectively.

he effect of the angle of the air stream on the pressure ribution is shown for one set of conditions in Fig. 4. The ation at the down-stream tapping with end-on flow may lue to a twist in the air-flow from the blower.

he mean values of these pressures around the gas passage, ever, do not show such large differences with direction. as been found that the results at all stream velocities and pling rates can be correlated by plotting the term (K/K_0) nst the ratio of stream velocity to sampling volume, re K_0 is the true instrument coefficient (i.e. in still air) and K is the measured instrument coefficient at the conditions of test. Fig. 5 shows this correlation, a subsidiary scale showing the equivalent free stream velocity for the normal sampling rate through the instrument. It will be seen from

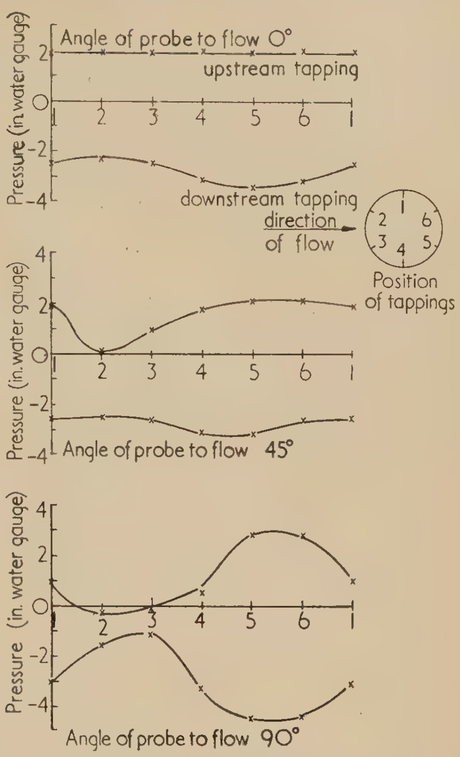


Fig. 4. Variation of pressure round hot Venturi with various angles of cross flow

Sampling rate 7·2 ft^3/min; stream velocity 50 ft/s.

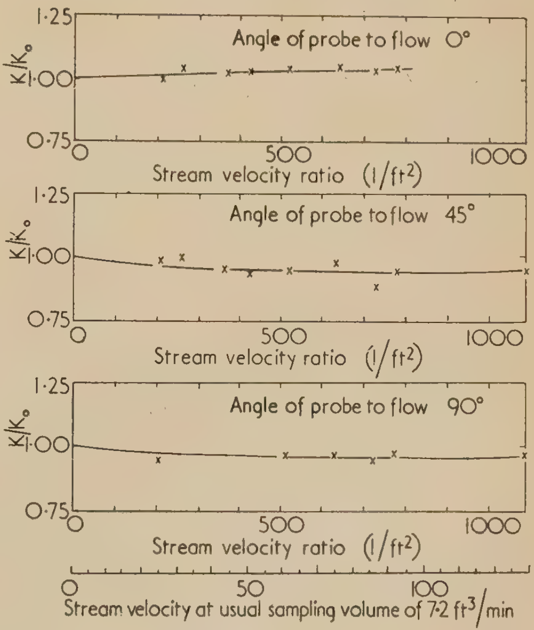


Fig. 5. Effect of stream velocity on observed reading of Venturi pneumatic pyrometer

[Stream velocity ratio = stream velocity (ft/s)/volume of hot gas sampled (ft^3/s).]

this curve that at a free stream velocity of 20 ft/s—a fairly representative upper limit for velocities in many industrial flues—changes in K and, hence, the error in the observed temperature in degrees absolute will vary from about plus 1% with end-on flow to −2% with cross flow and −3% with flow at 45° to the probe.

The probe. The degree of cooling of the gas is controlled by adjusting the amount of the inner tube inserted in the water cooling. Control by altering the gas flow is not recommended, as the sensitivity of the instrument decreases with a reduced gas flow. The gas temperature at the rear end should be kept as low as possible (usually 100–150° C), while avoiding any possibility of condensation; this would, besides altering the characteristics of the cold Venturi, directly affect the reading by the change in the mass flow between the two Venturis.

Similarly, it is necessary to keep the surface temperatures in contact with the gas above that of the dew-point temperature of the gas. Except at very low temperatures, the only point where this is likely to occur is on the water-cooled inside walls of the probe. This can generally be prevented by circulating the water along the outside of the probe first. Any condensation that does occur will, of course, tend to form its own insulating layer and a state of equilibrium will soon be reached.

When the probe is used at high temperatures overheating can cause problems, and it has been found advisable either to boost the water pressure to the cooling system or to put about a half inch layer of refractory insulation round the probe.

The cold Venturi. At a cold end temperature of 150° C, it is only necessary for this to be read to within $2\frac{1}{2}$° C to obtain a final temperature with an error from this cause of less than 1% (for gas temperatures above 500° C). A single chromel–alumel thermocouple is therefore adequate. The response of this thermocouple, however, determines the ultimate speed of response of the instrument. The sheath round the thermocouple should therefore be kept as thin as possible: in the present design the first $\frac{1}{2}$ in. of the thermocouple protrudes beyond the brass conduit, being coated with a thin varnish only. The whole Venturi section is well insulated, both to improve the accuracy of the temperature reading and to eliminate any significant temperature drop between the Venturi throat and the thermocouple. The error due to thermal expansion at the Venturi has been calculated and found to be less than $\frac{1}{2}$% at the recommended working temperatures.

4. PREPARATORY EXPERIMENTS

Calibration of direct indicating unit. The direct indicating unit is calibrated by the following procedure. The probe is inserted into a source of hot gas and connected to the indicating unit. The pressure drops Δp_1 and Δp_2 and the cold end temperature are recorded from the various indicators on the unit simultaneously with the reading of the final output from the computer in milliamperes. The term $[(\Delta p_1/\Delta p_2)/T_2]$ which, by equation (4), equals (T_1/K) can then be calculated and plotted against computer output over a range of gas temperature. It will be noticed that it is not necessary to obtain an independent measurement of the temperature of the hot gas in this procedure and hence a small source of hot gas can be used. Fig. 6 shows calibration curves for the unit used in this laboratory. Both visual and recorder output readings are plotted, the difference between the two being due to the first being read from a flickering needle while the other was taken from the charts. The various inter-relatio are linear and thus, once only a limited number of poin have been determined, the complete set of curves can extrapolated. The change in the range of the instrume obtained by altering the "hot end" reference source is show on the subsidiary curve.

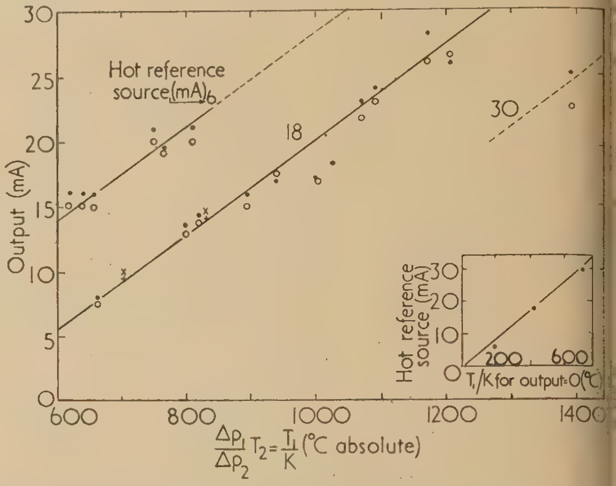


Fig. 6. Experimental calibration of direct indicating uni

Computer output: ● = probe A; × = probe B.
Recorder reading: ○ = probe A; + = probe B.

Determination of the instrument coefficient. The instrumen coefficient K, is determined by "cold flow" tests. Air at ro temperature is sucked through the instrument and the pressu drop through both Venturis determined. The instrumen coefficient is then given by the ratio of the pressure d through the cold Venturi to that through the hot. At th optimum pressure drop across the cold Venturi of 3 in. wat gauge, the pressure drop across the hot Venturi will, with th dimensions described in this paper, be only about 2 in. wat gauge. In order to ensure that the coefficient is determine within, say, ±2%, each pressure drop must be measured t within 0·025 in. water gauge and it is essential that gaug are used on which this accuracy can be obtained.

Unless the dimensions of the instrument are altered damage or chemical attack, there is no reason why the instr ment coefficient of the clean instrument should vary. Th fact provides a good means of checking that the instrumen is clean and correctly assembled before commencing test, being recommended that a "cold flow" check be alwa carried out just prior to inserting the probe in the furnace.

If the hot Venturi assembly is not tightened sufficiently, high coefficient will be observed. In one case examine easing the tightening thread a quarter of a turn increased by 16% while easing it three-quarters of a turn increased by 26%. Other causes of a large variation in the coefficien include blockage in the Venturi sections, either blockage leakage in the pressure lines, moisture in the pressure line or air leakage where the extending section slides into th water-cooled jacket.

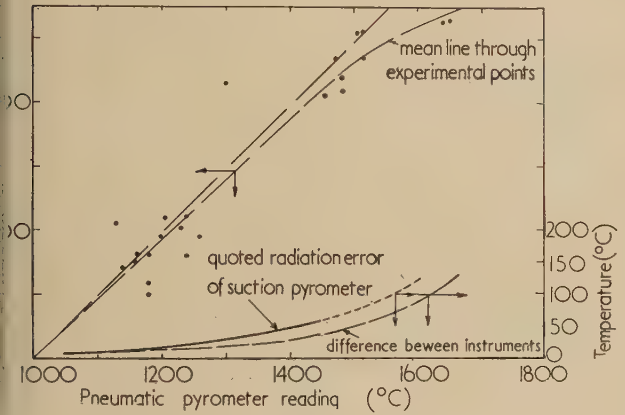
It is considered that the instrument coefficient should measured to, and remain constant within ±2·0%. There no reason to suppose that a change in the gas temperatu should alter this coefficient and evidence given later suppor this. The instrument is therefore direct-reading and does n depend upon a calibration against any other temperatu measuring device.

nould be emphasized that taking "cold flow" checks liately after use in a hot gas may lead to misleading owing to moisture condensing on the Venturi surfaces wing it from the furnace. Also, carrying out these near a furnace may lead to error owing to the ambient rature being higher than that of the cooling water and being cooled in passing down the probe.

MPARISON OF INSTRUMENT WITH SUCTION PYROMETER

etermination of the accuracy of the instrument in use nplicated by the difficulties of finding a source of hot a uniform, known temperature. In practice, the only vailable is to compare the instrument with some other rature measuring instrument on an industrial appliance. present case, this procedure is very difficult in the upper rature ranges owing to the absence of any other reliable d but comparisons are possible up to 1500–1600° C a suction pyrometer.

suction pyrometer used was that developed by Land neters Ltd., and the British Iron and Steel Research iation.(7) It is used extensively in preheated air streams ts accuracy up to 1300° C under these conditions has well established. Above temperatures of this order, diation error begins to increase rapidly and hence the ed correction, especially when used in flue gases, is asy to determine.



. 7. Comparison between observed suction pyro- ter and Venturi pneumatic readings in downtake of open-hearth furnace

compare this suction pyrometer with the Venturi natic pyrometer, both instruments were installed side le in the downtake of an open-hearth furnace, care being to ensure that both were in the region, previously nined, of constant temperature distribution. In this between the furnace and regenerators, hot air passing furnace is replaced by the waste gas leaving the furnace gular intervals. Simultaneous readings on both instrus were then taken both on preheated combustion air on the waste gases, the suction pyrometer only being intermittently on the waste gas to avoid the onset of age. The comparison between the uncorrected readings the suction pyrometer and pneumatic pyrometer is n in Fig. 7 and it will be seen that there is appreciable imental scatter.

is is due to the fact that the temperature in the downtake is changing continuously with time. Hence, the reading observed at any moment on an instrument is dependent on its speed of response. The pneumatic pyrometer has a speed of response of only a matter of seconds and can be expected to follow the temperature changes accurately, whilst the speed of response of the suction pyrometer is slower and some lag must be experienced. This is illustrated by Fig. 8, showing some observations on another regenerative furnace where it will be seen that the suction pyrometer gives a distorted picture of the true reversal curve.

The difference between the readings given by the suction pyrometer and the pneumatic pyrometer shown in Fig. 7 is shown by the curve at the bottom of this figure. This is compared with the estimated radiation error of the suction pyrometer and it will be seen that there is good agreement between the suction pyrometer temperatures, after these have been corrected for the radiation error, and the observed pneumatic pyrometer readings.

A very reliable spot comparison between the Venturi pneumatic pyrometer and the type of suction pyrometer used at the International Flame Research Station at Ijmuiden, Holland,(8) was carried out in the waste gases of a pulverized fuel flame. The instruments agreed to within ±30° C at 1370° C (±2% of the flame in ° C). The order of the rapid local temperature fluctuations as picked up by the Venturi pneumatic pyrometer was ±30° C whilst the error of the suction pyrometer was given as of the order of −20° C.

Attempts are being made to obtain comparisons between the pyrometer readings and optical measurements, though this is proving difficult owing to the practical problems of comparing a temperature traverse with a mean radiating temperature as is given by methods using optical or radiation pyrometers.

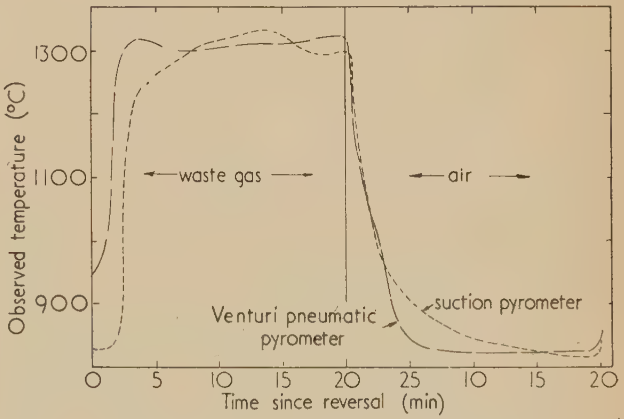


Fig. 8. Comparison of observed reversal patterns in the uptake of a regenerative furnace

6. THE USE OF THE INSTRUMENT

An appreciable amount of work has been carried out on various industrial furnaces and, while these give no formal confirmation of the accuracy of the pyrometer, the general agreement between the temperatures measured and anticipated—where this could be done—is satisfactory. It is hoped to make these investigations the subject of a further report, but Figs. 9 and 10 are given here as they illustrate the particular advantages of this instrument.

The most striking attribute of the instrument is that it can be used at higher temperatures than other probe instruments and it thus provides a means of measuring temperature contours which could previously only be deduced from theoretical or indirect considerations. For example, the temperature distribution in the flame of furnaces such as the open hearth can be measured. Fig. 9 summarizes some traverses obtained during a preliminary examination of such flames.

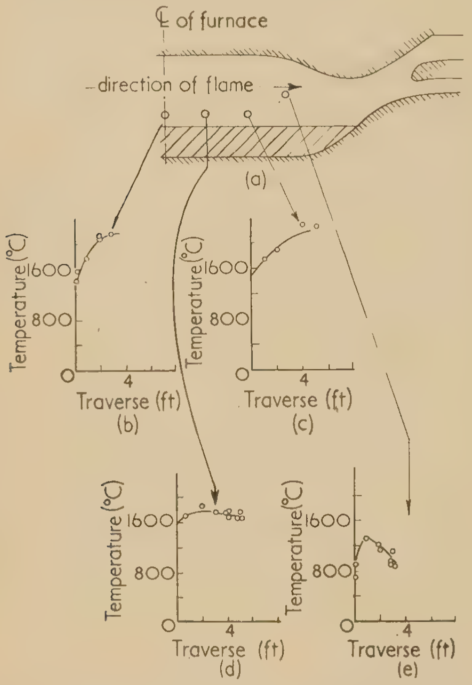


Fig. 9. Temperature traverses obtained with Venturi pneumatic pyrometer on producer gas-fired, open-hearth furnace

(*a*) Side elevation of furnace showing access holes.
(*b, c*) Air flow, 4·2 × 10^5 ft^3/h; gas flow, 2·6 × 10^5 ft^3/h.
(*d, e*) Air flow, 3·4 × 10^5 ft^3/h; gas flow, 2·6 × 10^5 ft^3/h.

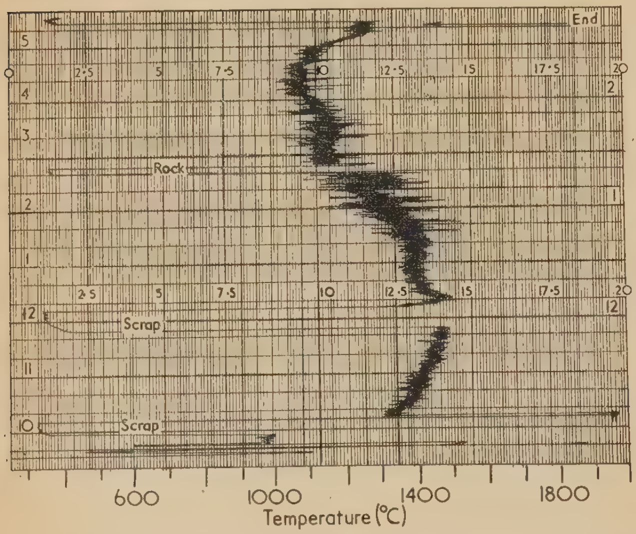


Fig. 10. Example of record obtained during trial on Bessemer converter

The rapid speed of response of the instrument makes useful in other cases where temperatures are low enough f other instruments, such as the suction pyrometer, to be use The use of the Venturi pneumatic pyrometer for measuri the shape of the reversal cycles in a regenerative furnace h already been illustrated in Fig. 8, while Fig. 10 shows actual record taken from the recorder giving the temperatu changes in the flame from a Bessemer converter used in ste making. The rates of reaction in this process are extreme rapid, and it has been found that the use of the pneuma pyrometer in obtaining an almost simultaneous record of t flame temperature changes is most valuable in studying th process.

Like all probe instruments, the Venturi pneumatic pyr meter is liable to blockage but it has been found to blo much more slowly than, for example, the suction pyromete and this again means that it can be used continuously f prolonged periods in situations where the suction pyrome can only be used intermittently. For example, it has b found that the Venturi pneumatic pyrometer will work f long periods in pulverized fuel flames. Surveys were carri out throughout the furnace at Ijmuiden in the tempera band 1300–1600° C, extending over about fifteen hours' ac testing time, without any cleaning being necessary other th the blowing out of loose dust. Similar results were obtain on a pulverized-fuel fired, water-cooled boiler. These t will be discussed in a later paper.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Moore, D. W. *Aero. Engng Rev.*, **7**, p. 30 (1948).
(2) Blackshear, P. L., Jr.: *Trans Amer. Soc. Mech. Eng* **75**, p. 51 (1953).
(3) Wildhack, W. A. *Rev. Sci. Instrum.*, **21**, p. 26 (1950).
(4) Godridge, A. M., Jackson, R., and Thurlow, G. *J. Sci. Instrum.*, **32**, pp. 279–81 (1955).
(5) Baulk, R. H. Private communication.
(6) Godridge, A. M., Jackson, R., and Thurlow, G. *Trans Soc. Instrum. Tech.*, **8**, (3), p. 103 (1956).
(7) Barber, R., and Land, T. *J. Iron and Steel Inst.*, **1** pp. 269–73 (1956).
(8) Hubbard, E. N. *J. Inst. F.*, **30**, pp. 564–76 (1957).

APPENDIX I

Notes on the theory of the pneumatic pyrometer

The effect of dissociation. It is assumed in Section that the ratio of the molecular weights of the gas at ea ri is unity. For a mixture of gases, the molecular t,

$$m = \Sigma_J \gamma_1 m_1$$

J is the number of components, γ_1 is the mass of any omponent per unit mass of gas and m_1 is the molecular t of this compound.

uld chemical reactions continue inside the probe en the two constrictions, then, assuming no change in takes place, the only effect on the temperature recorded e due to changes in the molecular weight of the gas. rror due to this cause for dissociated waste products of ducer gas flame has been estimated. Even if all the iated products reassociate in the probe, it may be seen the table that the total error at 2500° C will be less 5%, even though a heat release equal to 25% of the heat content will have taken place in the probe.

of dissociation on waste gas from combustion of producer gas

vsis by weight: CO_2, 25·73%; H_2O, 5·23%; N_2, 69·04%)

ature C)	% Dissociation* CO_2	H_2O	$(\Sigma_J\gamma_i m_i)_1/(\Sigma_J\gamma_i m_i)_2$	Latent heat of dissociation as % total heat content*
00	2·2	0·5	99·78	2·2
00	6·9	2·9	99·24	5·5
00	15·0	8·0	98·39	11·1
00	26·9	15·7	97·10	17·9
00	42·9	26·5	95·39	25·1

PIERS, H. M. (Ed.). *Technical Data on Fuel*, 5th ed., p. 440 lon: British National Committee, World Power Conference,

effect of reactive gases. Changes in the composition gas being sampled down to the probe may also occur sampling in a flame in which the chemical reactions are omplete. For complete accuracy, it would be necessary rry out an analysis of the gas entering and leaving the and where, as in a full furnace trial, the gas comion is being studied independently of this instrument, procedure would not cause undue complication. In al, though, it may be safely assumed that the rate of ng of the gas entering the probe is such as to quench the ions before they have proceeded much further, and errors er than 5% are unlikely to arise from this cause. It can own that the error will tend to give a low reading.

e effect of deviation from the gas laws. Deviations from as laws will have no significant effect at the pressures with in industrial furnaces. In so far as the temperature ded by the pneumatic pyrometer is that related to the ty of the gas, this temperature is that given by the lational energy of the molecules and will not be ted by energy other than that in flames not at thermal ibrium.

e effect of dust. The dust burdens in industrial gas will sufficient to affect the density of the gas and will have no eciable effect (assuming they do not deposit on the ces in the pyrometer) on the pressure drop. The dust nt of the gases sucked through the instrument will be r, in any case, than that in the main stream.

e effect of compressibility. Any influence of comibility of the gas will be small in the range of applications which the instrument has been designed, though conation may have to be given to this property in other mstances.

APPENDIX II

The Venturi pneumatic pyrometer direct indicating unit

The unit performs a continuous computation of gas temperature at the inlet to the probe (hot Venturi temperature). It consists of pressure and temperature transducers, reference current sources, a simple computer, indicators and associated power units. The reference and output indicators are contained in a box resting on anti-vibration mountings inside the framework.

Input signals in the form of gas pressure changes are converted by two differential pressure transducers into direct currents, and then fed into the simple computer. Cold Venturi temperature is measured by a thermocouple, the e.m.f. generated being amplified to a power level sufficient for application to the simple computer. Reference currents adjustable manually are derived from stabilized voltage sources. The output signal of the unit is a direct current in the range 0–30 mA, and is displayed on the output indicator contained in the unit. The output recorder is connected externally.

Differential pressure transducers. The differential pressure transducer is a force balance device using a diaphragm as the primary measuring element. The pneumatic force acting on the diaphragm is transmitted from the pressure chamber through a small diaphragm seal on to a compound lever system, which finally connects to a pivoted beam carrying at one end a pot coil working in the field of a permanent magnet, and also a contact which floats between two fixed contacts. The lever ratio is such that, under equilibrium conditions, the force of the measuring diaphragm is balanced by the repulsion force between the coil and the permanent magnet, owing to a current in the coil.

The moving contact is connected through a suitable circuit to the grid of a thermionic valve in the power unit, and the two fixed contacts carry grid bias potentials which serve to increase or decrease the anode current when touched by the moving contact.

Included in the anode circuit of the valve is the pot coil winding together with the internal indicator. When the diaphragm force balances the coil force, the moving contact floats free of both fixed contacts; but any unbalance causes it to touch one or other of the fixed contacts, so varying the grid cathode potential and hence changing the anode current in such a direction as to restore balance.

Temperature transducer. This device is primarily a d.c. amplifier in which a beam of light is reflected *via* a sensitive mirror galvanometer on to a photocell connected in the grid circuit of a thyratron valve.

The galvanometer is deflected by the e.m.f. generated from a thermocouple, and causes a change in light falling on the photocell, the resistance of which changes and alters the phase of the grid voltage applied to the thyratron. This makes a change in the thyratron firing angle, and thus in the d.c. current, which is fed back through standard resistance connected in the thermocouple input circuit in such a sense that the e.m.f. developed across the standard resistance opposes the e.m.f. generated by the thermocouple.

A cold junction compensation circuit is provided, which adds the appropriate e.m.f. into the thermocouple circuit, and refers the readings to the normal cold junction temperature of 0° C.

Reference current sources. These are neon stabilized sources supplying current in the range 0–30 mA, d.c., and are adjustable by means of wire-wound potentiometers located on the Perspex cover of the housing of the indicators.

The simple computer. The simple computer is an analogue device providing a continuous output signal which is an algebraic function of one or more input signals. In the application described, the operations of addition, subtraction, multiplication and division are performed simultaneously on the signals derived from transducers and reference sources.

The principle of operation is similar to that of the differential pressure transducers described above. A pivoted beam carrying a pot coil at each end is subjected to the torques developed by the interaction of signal currents (carried by the pot coils and electromagnet windings). As a result the beam is displaced from its equilibrium positi This results in a change in the anode current of a valve whic is fed back to restore the beam to balance.

The computer consists of (i) the computing relay, a (ii) the power unit. The relay consists of the beam, with p double-wound coils, centre contact, and control sprin Mumetal electromagnets and the biasing contacts. Th power unit contains a bridge rectifier, a thermionic valve, grid network and a biasing network. It is constructed tray form with plug-in connexions and is installed on a rac together with identical power unit serving differential pressu transducers.

A nuclear magnetometer

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[*Paper received* 19 *August*, 1957]

The basic principles of the nuclear free precession magnetometer are briefly described, and full details given of the coils, switching circuits and transistorized amplifying equipment of such a magnetometer. Accuracy of absolute measurement of the earth's total field is $\pm 10\,\mu$G, and even better when only relative measurements are required. Setting-up of the instrument, which requires no calibration, and taking a reading takes only a few seconds. Suggestions are put forward for possible further applications of the free precession technique.

In his classic paper on nuclear induction, Bloch(1) remarked that the direct observation of nuclear induction should be possible, although his paper presented only the results obtained by resonance methods. It was not until recently that Packard(2) and Waters(3, 4) reported the successful accomplishment of this experiment.

Because of the potential value of this method of measuring the earth's total magnetic field to observatories, geophysical survey parties and as a University demonstration, details of the apparatus and results obtainable are given here.

PRINCIPLE

When a system of nuclear spins is placed in a magnetic field H, the thermal equilibrium established between the spins and their surroundings results in a small magnetization M parallel to H. The resultant magnetic moment M per unit volume of the sample is given by

$$M = \chi H \tag{1}$$

where χ is the nuclear susceptibility of the sample.

So long as the energy of magnetization μH is small compared with the energy of thermal agitation kT, this susceptibility is given by the Curie formula

$$\chi = \frac{j+1}{3j}\,\frac{n\mu^2}{kT} \tag{2}$$

where μ = magnetic moment of the nucleus, n = number of nuclei/cm^3; j = angular momentum in units of $h/2\pi$; k = Boltzmann's constant; h = Planck's constant; and T = absolute temperature.

Consider that a sample containing suitable nuclei, situated in the earth's total magnetic field F, has applied to it, at an angle to the earth's field direction, a d.c. magnetic field H many times stronger than that of the earth's field. The resultant field across the sample will, if $H \gg F$, hav direction and strength approximately equal to H. After finite time, equilibrium is reached with the nuclear m netization in the sample having the value given M b equation (1).

If the field H is then suddenly removed, so that only field remains, because of the gyromagnetic properties of the nucl which make up the magnetization M, this resultant ma netization vector will precess about the field direction before the nuclear spins reach their new equilibri alinement.

The rotating flux associated with the precessing magnetiz tion vector M will induce a small e.m.f. in a suitably oriente pick-up coil about the sample. The frequency of this alte nating e.m.f. will be that of the rotating flux which, in turn is the Larmor precession of the particular nuclei in the residu field, i.e. the earth's field. The Larmor precession frequen f in a field F of a nucleus of gyromagnetic ratio γ is given b

$$2\pi f = \gamma F \qquad (\,$$

In consequence, if the gyromagnetic ratio of the nucle being used is known, the measurement of the frequency the signal generated in the pick-up coil enables the streng of the field to be determined. If protons are used, as f example with a water sample, the precession frequency f the earth's magnetic field in Great Britain ($F \simeq 0{\cdot}5$ G) about 2000 c/s ($\gamma_p = 26\,753{\cdot}0\ \mathrm{s^{-1}\,G^{-1}}$).

However, since a determination of frequency is involve accurate measurement necessitates a reasonable period signal for observation, and it is because of the relatively lo decay times which can be achieved in this experiment that has real practical value.

The relaxation times involved are the spin lattice relaxati time T_1, and the spin spin relaxation time T_2, defined and use extensively in nuclear magnetic resonance literature.(1) I this particular context, the growth of nuclear magnetizatio sample on application of an external field is exponential, time constant T_1, i.e. magnetization M_t, at t seconds applying field H is given by

$$M_t = M(1 - e^{-t/T_1}) \qquad (4)$$

M is the equilibrium value given by

$$M = \chi H$$

n the other hand, is the time constant of the decay of oherent state of magnetization and determines the tude of the induced e.m.f. It is usual to denote this constant by T_2 only when the decay rate is determined by the intrinsic properties of the sample, and by T_2^* instrumental factors influence the decay.

s somewhat surprising to find that these decay rates in liquids can be of the order of seconds, whereas in the sponding case of atomic paramagnetism these times are shorter and establishment and decay of electronic etization is virtually instantaneous. This is attributable e small interaction between one nucleus and its neigh-, and with the atomic lattice, such that loss of energy the nuclei is a slow process.

s of interest to calculate the magnitude of induced e.m.f. might be expected in a practical case. Consider a m^3 sample of water, in which are $6 \cdot 9 \times 10^{22}$ protons/cm^3, with a magnetic moment equal to $1 \cdot 4 \times 10^{-23}$ c.g.s.

ce $j = \frac{1}{2}$ for the proton, if a field H of 100 oersted is ed to the sample, when its temperature is 291° K the ar magnetization M is equal to $1 \cdot 7 \times 10^{-5}$ c.g.s. units. this magnetization precesses at frequency f in a coil of rns and cross-section area A the voltage induced in the vill be

$$V = \frac{1}{c}\frac{d\phi}{dt} = \frac{1}{c} \cdot \frac{d}{dt}(4\pi M \sin 2\pi \text{ ft} . N.A.\alpha)$$

e α is the filling factor.

us for a coil of 1000 turns, radius 5 cm and assuming be $0 \cdot 5$, and with f in the earth's field in England oximately 2000 c/s

$$V \simeq 3 \cdot 5 \ \mu V$$

e practical problem is therefore one of detecting a few ovolts at approximately 2000 c/s. Since the decay time ie signal is of the order of a second or so, the band- of the amplifying stages need only be a few cycles econd for faithful reproduction of the decaying signal, by reducing the thermal noise background to a minimum. iere is one more theoretical point to be considered, ely, the conditions that must be observed in removing olarizing field so that precession takes place. When the rizing field is applied, the nuclei see the resultant of this the earth's field. Removal of this polarizing field reduces nagnitude of this resultant field from approximately that ie polarizing field to that of the earth's field, and the tion of this resultant changes from that of the polarizing through a right angle to the earth's field direction. The of change of direction will be most rapid when the ual value of the polarizing field approaches and equals of the earth's field.

has already been stated that the spin lattice relaxation is long, and consequently, once the magnetization is olished in the sample by a field, this value of magnetization be retained for a considerable period irrespective of ges in strength of field. However, because of the gyromagnetic properties of the contributing nuclei, a change of direction of the polarizing field is more critical. If the direction of field is changed by an angle ϕ in a time which is long compared with a precession period of the nuclei in that field, then the resultant magnetization vector follows faithfully the direction of the controlling field. If, however, this change of direction is accomplished in a time short compared with a Larmor precession period, precession takes place. Conditions are analogous to those of the mechanical gyroscope. In quantum nomenclature, this rapid change of field direction is referred to as the "non-adiabatic" change, from the wave mechanical extension of Ehrenfest's adiabatic principle.

In practice, reduction of the polarizing field from 100 to 2 oersted can be comparatively slow (although much less than T_1), but collapse from 2 oersted to zero must be very short compared with a precession period at 2 oersted which will be about 120 μs. This necessitates final current collapse in perhaps 30 μs or less.

With such a coil system, if underdamped, the fall of the current will be oscillatory, reaching first zero after a quarter period of the ringing frequency. If this time is short enough (i.e. very much less than the precession period) the non-adiabatic condition is satisfied. The subsequent high-frequency oscillatory ringing current and associated magnetic field, will, on the same argument, not seriously perturb the precession. Since the mean value of the oscillatory magnetic field will be zero, it will not introduce any possible error in the measurement of the earth's field at the sample.

It follows, therefore, that the coil and associated circuit should have a high natural ringing frequency such that a quarter period is less than 30 μs. The ringing frequency should therefore be greater than 8 kc/s.

APPARATUS

A block diagram of the complete nuclear magnetometer is given in Fig. 1. The main elements are the coil assembly, switching unit, amplifiers, display and counter. These will be described in turn.

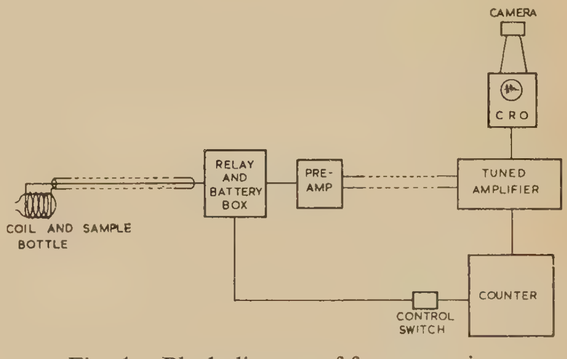

Fig. 1. Block diagram of free precession magnetometer

Coil assembly. In early experiments, a double coil unit was used with separate coils to produce the polarizing field and for signal pick-up. These were arranged so that the two coil axes and the earth's total field direction were mutually perpendicular. The polarizing coil, which was the outer, consisted of 200 turns of 13 s.w.g. enamelled copper with inside coil diameter of 10 cm. A current of $12 \cdot 8$ A was required from a 12 V accumulator to produce the 100 oersted polarizing field, and although early success was achieved with complicated electronic switching using a subsidiary holding field of 2 oersted, it was found that breaking the current with a suitable heavy duty switch or relay was adequate. The pick-up coil in this system was then a wave-wound coil, wound in two banks of 500 turns each, close to the water sample in the centre of the coil assembly. Coaxial cable from this coil went straight to the pre-amplifier.

At a later stage it was found expedient to combine the two coils as one, since the rotating flux links equally well with the polarizing coil as well as the pick-up coil. Many coils of different dimensions and electrical characteristics have been tried, and the best design depends on several factors including conditions under which the instrument is to be used.

Broadly speaking, the major requirements are: (i) large number of turns; (ii) low self-capacitance; (iii) high "Q" factor; and (iv) large volume inside coil. The first two requirements are to ensure good polarizing field and rapid switch-off, the others to ensure maximum signal voltage.

One satisfactory design that has been employed has the following characteristics: sample 250 cm^3 plastic bottle, filled with distilled water; coil 1000 turns of four separate banks of 250 turns each $\frac{3}{4}$ in. wide; 26 s.w.g. single-cotton covered enamelled copper; spaced approximately $\frac{1}{8}$ in. apart and cemented into position; leads brought out on Uniradio 70.

There is nothing that is critical in this design. As far as sample materials are concerned, it is convenient to make use of the proton magnetic moment which is large, but other nuclei could be used, e.g. fluorine, but that will give a slightly higher precession frequency. A sample of hydrogen fluoride will give a precession signal that exhibits a beat note of 185 c/s on the decay envelope, owing to super-position of hydrogen and fluorine signals.

Of hydrogen-containing liquids, those with a high concentration of hydrogen are most favourable, e.g. water, benzene, alcohol, and so long as these liquids are free from paramagnetic impurities good signals with decay times of a second or two can be achieved. Tap-water and sea-water have been used successfully, and by totally immersing the coil in water an increase in filling factor can be achieved.

It has been shown recently that the relaxation time T_2 of about three seconds observed for these liquids is partly due to the presence of dissolved oxygen which is paramagnetic, and removal of some or all of this ozygen will result in considerably longer decay times. This can be done by vacuum distillation or bubbling nitrogen through the sample for a period.

Switching circuits. The switching circuits for the double and single coil assemblies are shown in Fig. 2. Fig. 2(*a*) shows that the d.c. circuit to the polarizing coil is broken by a heavy duty relay (by British Thomson-Houston Ltd. or Magnetic Devices Ltd.) with 25 A contacts. The mechanism of the switch-off may be rather complex, as the attempt to reduce the current in the inductive circuit establishes a large back e.m.f. which causes arcing at the switch contacts. While this arc is maintained, the arc current flows and gives rise to a holding field along the coil axis. It is the final collapse of the arc which will constitute the rapid switch-off, and allow precession to start. This arcing is undesirable in that there is heavy wear on the contacts, but suppression is liable to remove the conditions needed for precession to take place. Use of Metrosil (by Metropolitan-Vickers Ltd.), or similar non-linear resistive elements should prove satisfactory.

Since the pick-up coil and polarizing coil are at right angles, attenuation of the pulse generated on switch-off into the signal coil is sufficient to allow the amplifier to be left in circuit throughout.

In the circuit for the single coil, it is preferable for amplifier to be isolated from the main coil during the switc off, as a back e.m.f. of several kilovolts may be generated.

Because of the large number of turns on the coil only small current is required for polarizing (approximately 1 A and Post Office relays with 2·5 A contacts can be used f the main circuit-breaker. In addition, a slow release rela is used to connect the coil to the amplifier, several millisecon after the polarizing circuit has been broken. It has also be found desirable to short out the amplifier input termina during switch-off, in order to reduce break-through and prevent the tuning condenser charging up prior to connectin coil terminals to the amplifier.

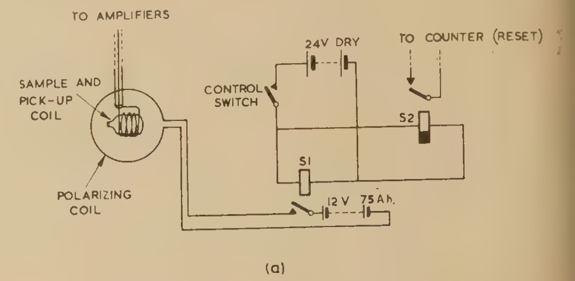

Fig. 2(*a*). Switching circuit for double coil

*S*1, B.T.H. heavy duty relay, 25 A contacts; *S*2, relay typ SM3, LV 79 (slow release).

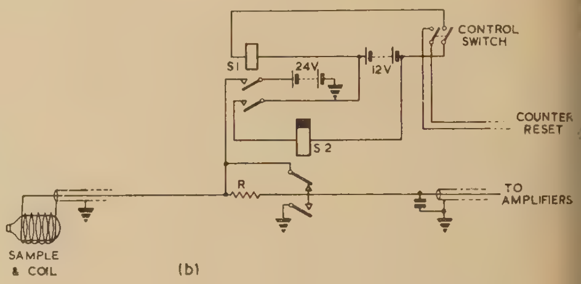

Fig. 2(*b*). Switching circuit for single coil

*S*1, relay type SM3 HV 45; *S*2, relay type SM3 LV 76 (slo release); *R*, 47 kΩ.

A later modification was the placing of a damping resist across the coil leads in the interval between switch-off a opening the amplifier. By doing this it has been found po sible to obtain consistent signals with the coil up to 200 length of Uniradio 70, whereas without the resisto consecutive signals varied considerably.

Amplifiers. In many purposes, it has been found desirab to have a low-noise pre-amplifier relatively near the switchi unit, so that a signal of a millivolt or so can be passed dow line of reasonable length to the main amplifier and frequen measuring equipment. There is no fundamental necessi for the amplifier to be in two sections, but if lumped togeth on one chassis special care must be taken to avoid instabili due to the high gain and high selectivity. Circuit diagra are given of both transistor pre-amplifier and main ampli (Figs. 3 and 4).

The pre-amplifier was designed to give: (i) low noise keeping the collector current low; (ii) high input impedan to avoid damping the signal coil; and (iii) good temperatu independence over a fair seasonal variation. Some selecti of transistors was necessary to keep the noise level down, ent gain was applied to see noise from the first stage. ms likely that recent developments in transistor design enable a much better preamplifier to be made. Finally, verall signal-to-noise voltage ratio achieved with the lete transistor amplifier chain was about one half that original thermionic valve circuits, but was still high

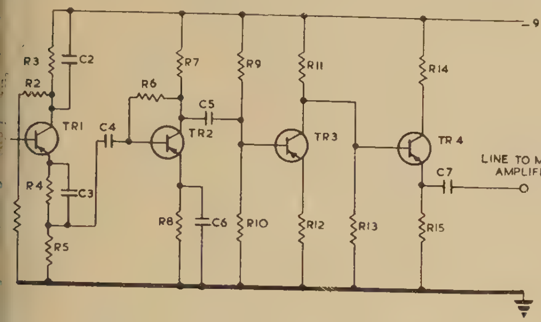
−9 V
R3
C2
R2
R6
R7
R9
R11
R14
C5
TR1
C4
TR2
TR3
TR 4
LINE TO MAIN AMPLIFIER
C7
R4
C3
R8
C6
R10
R12
R13
R15
R5

Fig. 3. Circuit of pre-amplifier

Voltage gain, 200; input impedance, 30 kΩ.

$R_1 = 150$ kΩ
$R_2 = 220$ kΩ
$R_3 = 51$ kΩ
$R_4 = 5{\cdot}1$ kΩ
$R_5 = 10$ kΩ
$R_6 = 150$ kΩ
$R_7 = 20$ kΩ
$R_8 = 2$ kΩ
$R_9 = 100$ kΩ
$R_{10} = 10$ kΩ
$R_{11} = 20$ kΩ
$R_{12} = 2$ kΩ
$R_{13} = 100$ kΩ
$R_{14} = 15$ kΩ
$R_{15} = 5{\cdot}1$ kΩ

$C_1, C_2 = 0{\cdot}05\ \mu$F
$C_3 = 50\ \mu$F
$C_4, C_5 = 0{\cdot}05\ \mu$F
$C_6 = 50\ \mu$F
$C_7, C_8 = 0{\cdot}1\ \mu$F

TRI–4 = Mullard O.C. 70

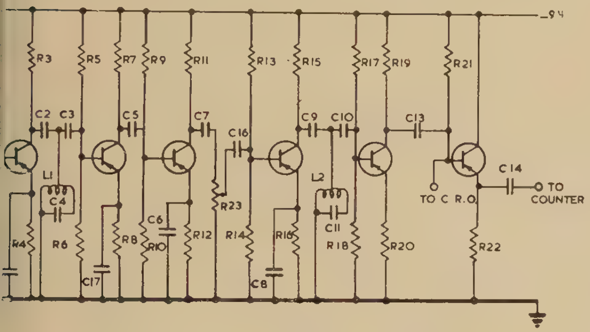
−9V
R3
R5
R7
R9
R11
R13
R15
R17
R19
R21
C2 C3
C5
C7
C16
C9 C10
C13
C14
TO COUNTER
TO C R.O.
L1
C4
L2
R23
C6
C11
R4
R6
R8
R10
R12
R14
R16
R18
R20
R22
C17
C8

Fig. 4. Circuit of main amplifier

Maximum voltage gain, 3×10^4; bandwidth, 30 c/s.

$R_1 = 33$ kΩ
$R_2, R_3 = 10$ kΩ
$R_4 = 4{\cdot}7$ kΩ
R_5 33 kΩ
$R_6 = 10$ kΩ
$R_7 = 4{\cdot}7$ kΩ
$R_8 = 1{\cdot}5$ kΩ
$R_9 = 33$ kΩ
$R_{10}, R_{11} = 10$ kΩ
$R_{12} = 1{\cdot}5$ kΩ
$R_{13} = 33$ kΩ
$R_{14}, R_{15} = 10$ kΩ
$R_{16} = 4{\cdot}7$ kΩ
$R_{17} = 33$ kΩ
$R_{18} = 10$ kΩ
$R_{19} = 4{\cdot}7$ kΩ
$R_{20} = 1{\cdot}5$ kΩ
$R_{21} = 33$ kΩ
$R_{22} = 1{\cdot}5$ kΩ

$R_{23} = 5$ kΩ potentiometer

$C_1, C_2, C_3 = 0{\cdot}1\ \mu$F
C_4 = to tune with L_1 at desired centre frequency
$C_5 = 0{\cdot}1\ \mu$F
$C_6 = 1{\cdot}0\ \mu$F
$C_7 = 0{\cdot}1\ \mu$F
$C_8 = 1{\cdot}0\ \mu$F
$C_9, C_{10} = 0{\cdot}1\ \mu$F
C_{11} = to tune with L_2 at desired centre frequency
$C_{12} = 1{\cdot}0\ \mu$F
$C_{13} = 0{\cdot}1\ \mu$F
C_{14}–$C_{17} = 1{\cdot}0\ \mu$F

L_1, L_2 = ferroxcube

TRI–6 = Mullard O.C. 70

gh to enable the counting accuracy of 1 part in 10^5 to aintained.

e input impedance was kept to 30 kΩ by use of a grounded ctor stage, and fairly heavy temperature stabilization ncluded in each stage. The main amplifier was straightrd in design, ferroxcube coils being used for tuning. l selectivity was maintained by matching the transistors the coils by a 1 : 10 tapping. A bandwidth of about s was achieved and the centre frequency switched by C_4 and C_{11}. The overall voltage gain of the amplifier was about 3×10^4.

Display. The signal has been displayed on a Cossor oscilloscope type 1049 fitted with 89L long after-glow tube. With the time-base set to 1500 ms, the envelope of the signal is painted on the tube and lasts for several traces, each successive trace being a portion of the exponential decay of smaller amplitude than the previous one. Crude visual estimates of signal-to-noise ratio and decay time T_2 or T_2^* can be made from this display.

For permanent record, the signal was photographed using the Cossor camera attachment with motor drive. In this case the time-base was switched off, the tube spot adjusted to be in the centre of the field of view and the camera drive set to run at suitable speed, e.g. 1 in./s. The decay curve shown in Fig. 5 was taken by this means.

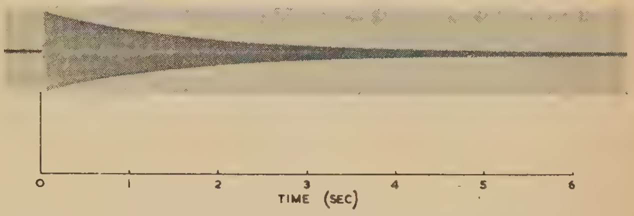

Fig. 5. Envelope of decaying free precession signal (protons in water). (2000 c/s not resolved.)

The same technique was used at an early stage of the experiments to measure the frequency. A standard 2 kc/s signal derived from a 1 kc/s valve maintained tuning fork was injected with the signal early in the amplifier and the display pattern then exhibited a beat note. This decaying trace with beat pattern was photographed, together with a 50 c/s timing signal displayed on the Y_2 trace, this time running the camera drive faster. Although this was a relatively tedious method, high accuracy was obtainable for values of the earth's field.(3)

Frequency monitor. It was appreciated that to be of real practical value, a virtually instantaneous and direct reading of frequency was essential, and any direct frequency measuring technique counting the number of cycles in a fixed time interval would necessarily be limited in its accuracy, as the duration of good signal/noise might be no more than 3 s. Accuracy by this method could not be better than one part in 6000. It was necessary, therefore, to adopt the alternative technique of counting off a fixed number of cycles, thereby

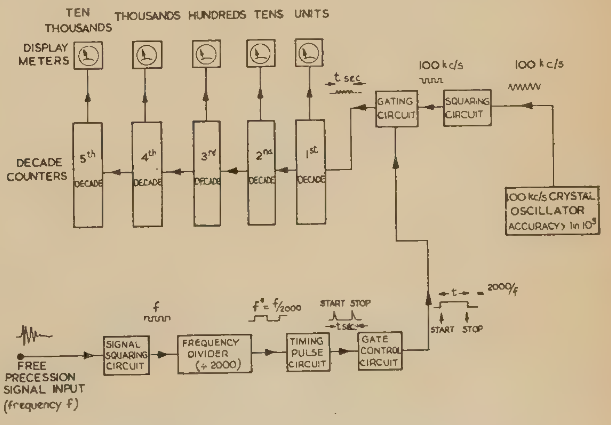
TEN THOUSANDS
THOUSANDS
HUNDREDS
TENS
UNITS
DISPLAY METERS
DECADE COUNTERS
5th DECADE
4th DECADE
3rd DECADE
2nd DECADE
1st DECADE
t sec
GATING CIRCUIT
100 kc/s
SQUARING CIRCUIT
100 kc/s
100 kc/s CRYSTAL OSCILLATOR ACCURACY > 1 in 10⁵
t = 2000/f
START
STOP
f
f' = f/2000
START STOP
t sec
FREE PRECESSION SIGNAL INPUT (frequency f)
SIGNAL SQUARING CIRCUIT
FREQUENCY DIVIDER (÷ 2000)
TIMING PULSE CIRCUIT
GATE CONTROL CIRCUIT

Fig. 6. Simplified block diagram of counter chronometer

providing a time gate to a counter chronometer. This provided the incentive for a fully transistorized counter chronometer to be developed. Full details of this are to be published elsewhere at an early date,(5) but a block diagram of its main components is shown in Fig. 6. The signal is squared and passed into a binary chain of eleven stages. This would normally produce one pulse out of every 2048 cycles at the input. However, for convenience, feedback loops are incorporated to reduce this to one every 2000. A variable delay is incorporated so that a start pulse is not produced until after 125, 250 or 500 cycles have passed and the stop pulse 2000 cycles later. The reference source is a 100 kc/s crystal which passes pulses through five decades for the duration of the gating interval. The meters would therefore read 00000 (i.e. 100 000 counted) if the frequency of signal was exactly 2000 c/s, and a change of one unit corresponds to a change of one part in 100 000, i.e. 0·02 c/s in the precession frequency. This corresponds to approximately 5 μG in the earth's total field. As an indication of the potential accuracy of the equipment, Fig. 7 shows the diurnal variation of the earth's field recorded at Christchurch compared with data taken from Royal Greenwich Observatory records for the same day. Total power consumption of the counter from a 12 V battery is 1 W.

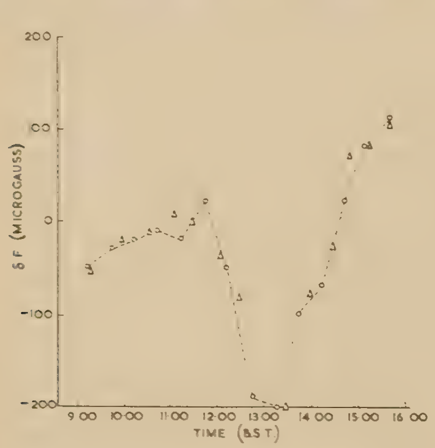

Fig. 7. Diurnal variation in earth's total magnetic field

○ . . . ○, Abinger data (half-hourly);
Δ Δ, nuclear magneto- meter readings.

ACCURACY

The measurement of the strength of the earth's total field depends on two factors, the nuclear constant γ_p and the frequency of precession. For the proton, the gyromagnetic ratio has been measured to one part in 40 000, and this will put a limitation on absolute determinations of F to ± 10 μG.

However, for relative measurements the accuracy of frequency is the limiting factor. The major source of error lies in the noise fluctuations superimposed on the signal. The frequency is measured by deriving a time gate from two cross-over points of the alternating e.m.f., and these will have an indeterminancy due to random noise. In a decaying signal the error introduced will become progressively greater as the signal amplitude is reduced. On the other hand, for a continuous alternating waveform, the accuracy of frequency measurement increases as the number of cycles counted is increased. For the decaying signal there is obviously a compromise and it can be shown that the optimum count period for an exponentially decaying signal is equal to the time constant of the decay. In this case T varied betwe one and three seconds and the counter was therefore design to count for 2000 cycles (approximately 1 s). Shorter cou periods were also incorporated for special operati conditions.

The error introduced by the noise fluctuation can be eas assessed, and for a signal-to-noise voltage ratio of 10 : 1, t probable error in frequency by counting 2000 cycles is o in 120 000. Consequently on these grounds the claim accuracy for relative field measurement of one in 100 000 valid if the signal/noise ratio at the end of the count peri is better than 10 : 1.

With the complete transistor equipment described in th paper, the signal-to-noise voltage ratio was 25 : 1 at t start of the decay, and under low field gradient conditio such that T_2^* was greater than 2 s, better than 15 : 1 after Accuracy is therefore limited by the 100 kc/s counter.

With the hard valve amplifiers and larger coils used earlier experiments, signal-to-noise ratios of better t 40 : 1 after 1 s were obtained. Under these conditions count over a period of 3 s would be possible and an impro ment in the accuracy by a factor of three achieved. A natively, a megacycle counter could be used with advan over 1 s. Such high accuracy is of little value, however, portable equipment for geophysical purposes.

It is obvious that with improved signal-to-noise ratio, longer decay times which are obtainable under favour conditions, it should be possible to carry out fresh de minations of γ_p. It is believed that the National Burea Standards is considering such a determination.

APPLICATIONS

As a magnetometer, the major advantages lie in the plicity, cheapness, and ruggedness of the head assem which needs no orientation or alinement before takin reading. An absolute value of the total field strength obtained by simple conversion from the dial readings, no temperature dependence or drift. As such, it will doubt be used extensively as an observatory instrume although it does not lend itself readily to measurement field direction.

Using the circuit described, a portable instrument readily be constructed enabling one man to carry out grou surveys, taking readings as frequently as he can chan location. Operating time is only a few seconds. Use of similar base station would enable corrections for diur variation to be made.

The form of the information lends itself readily to tra mission over normal communication channels, either by li or radio. In the authors' case, signals have been fed from t pre-amplifier into field telephone lines, and frequency measu ments made remote from the survey site. Similarly, t precession signal can be used to modulate a transmitter a the information telemetered back over long range. Expe ments with a balloon-borne instrument over ranges up 200 miles have been reported.(6)

For airborne surveying, as is done currently by the fluxga type of magnetometer, the nuclear magnetometer is ide Being relatively independent of orientation, no expens stabilizing elements are required for the towed "bird," on a bottle of water and a coil! If frequent readings are requir with fairly fast aircraft, it may be necessary to use a ve dilute paramagnetic solution as a sample, with some loss accuracy. The use of a liquid with shorter T_1 enables t polarizing period to be shortened to perhaps half a secon he counting period would also be shorter because of the decay, thereby reducing the accuracy by a small factor. geophysical survey purpose an accuracy of ±20 μG is lly adequate. It is understood that Hycon Aerial Surveys alifornia are already flying such an instrument developed arian Associates.

e experiment itself with the display of the decay trace is onsiderable value in demonstrating nuclear spin effects, articular the two relaxation times. It is necessary to e the coil assembly in a region of good field homogeneity, this precludes having the whole apparatus inside a atory. However, with a 200 ft lead to the coil, it is lly possible to find a site clear of magnetic anomalies pipes, steel-framed buildings, etc.) retaining the uring apparatus under cover.

e effect of field inhomogeneity is to reduce T_2^*, and the y time can be used as a crude magnetic gradiometer. ge of measurement will depend on the coil geometry, but a typical coil, gradients in the range 1 to 60 μG/cm been measured. For smaller gradients, down to μG/cm two coils on a fixed base and parallel amplifier nels, with a frequency comparison system can be used.

study of the intrinsic properties of the liquid samples selves is of considerable interest. The natural T_2 of the d, which is observed if field homogeneity at the sample is l enough, depends amongst other things on rapidity otion of adjacent molecules, and hence is a function of osity.(7) It is possible that this might prove a useful shearing method for measuring viscosity in certain ds, e.g. motor oils.

On the other hand, T_1 is dependent on the concentration of paramagnetic ions in solution, and might be used as a measure of this concentration. For example, T_1 for 0·001 N solution of ferric nitrate is 0·8 s, whereas for distilled water, T_1 is 2·3 s. Measurement of T_1 is readily achieved by plotting the initial amplitude of precession signal against the time for which the polarizing field was applied. A curve of the form of equation (4) is obtained.

ACKNOWLEDGEMENT

We would like to express our indebtedness to Mr. G. Phillips, who inspired this work from the outset and with whom many stimulating and fruitful discussions have been held.

REFERENCES

(1) Bloch, F. *Phys. Rev.*, **70**, p. 460 (1946).

(2) Packard, M., and Varian, R. *Phys. Rev.*, **93**, p. 941 (1954).

(3) Waters, G. S. *Nature* [*London*], **176**, p. 691 (1955).

(4) Waters, G. S., and Phillips, G. *Geophys. Prospecting*, No. 1 (1956).

(5) Bradshaw, C. G. To be published.

(6) Cahill, L. J., and Van Allen, J. A. *J. Geophys. Res.*, **61**, (3), (1956).

(7) Bloembergen, N., Purcell, E. M., and Pound, R. V., *Phys. Rev.*, **73**, p. 679 (1948).

The emergent column correction in mercury thermometry

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The conditions which determine the accuracy of measurement of the emergent column temperature when mercury thermometers are used at partial immersion are discussed. The method of measuring the emergent column temperature used at the National Physical Laboratory is described, a table of the average values experienced is given, and the reasons in favour of testing thermometers at the immersion at which they are to be used are explained.

he highest possible accuracy is to be obtained from a cury thermometer, it must be used with the whole of the cury at the temperature to be measured. If it is only ially immersed, the readings will depend on the tem- ature of the emergent column, and, as it is not easy to sure this temperature, there is inevitably some loss of racy.

With a thermometer calibrated for total immersion, the ection to be applied when it is only partially immersed is n by $\alpha n(t - t_s)$, where α is the expansion coefficient of cury relative to the glass of the thermometer, n is the th of the exposed mercury column measured in degrees, t he temperature to be measured and t_s the temperature of exposed column. In general, there will be a large tem- ture gradient along the column, and the mean tem- ture is required. This will depend on the following ors: (i) the temperature of the enclosure which is being sured, (ii) the rate of heat loss from the top of the osure for a given temperature (it is assumed that the thermometer is being used vertically), (iii) the atmospheric temperature some distance above the enclosure, (iv) the length of the exposed column and (v) conduction along the thermometer stem.

Experiments carried out at the National Physical Laboratory some years ago(1) showed that (v) is not very serious and that reasonably satisfactory results are obtained if the mean temperature of the air surrounding the exposed column is carefully measured. It is clear that if the column is very short (i) is the predominant factor, and as the column is lengthened (iii) becomes progressively more important. The form of the gradient along the column is largely controlled by (ii). This is shown by the two curves of Fig. 1 which represent the gradients along the columns of thermometers in a water bath at 85° C and in a hypsometer at 100° C. In the water bath the upper surface of the enclosure is a brass plate washed by the water (Fig. 2), and at high temperatures a fair amount of steam rises from this. In the hypsometer, in order to prevent excessive emission of steam, the top of the apparatus is covered with asbestos paper, through which the thermometers are pushed. The consequent reduction in heat flow leads to a much sharper fall of temperature just above the immersion level.

ACCURACY OF THE EMERGENT COLUMN CORRECTION

Since the magnitude of the correction is proportional to $(t - t_s)$ and t is known exactly, then, for a given value of t, the uncertainty in the correction is given by $\alpha n(\Delta t_s)$, where Δt_s is the uncertainty in t_s. If, however, the thermometer is intended for use at a fixed immersion, it may be calibrated at that immersion. The correction then takes the form $\alpha n(t_{s1} - t_{s2})$, where t_{s1} and t_{s2} are the stem temperatures during calibration and use respectively, and frequently t_{s1} and t_{s2} will be so nearly alike that the correction may be neglected. If this is not the case, the uncertainty in the correction is given by $\alpha n(\Delta t_{s2} - \Delta t_{s1})$, and, if t_{s1} and t_{s2} are measured in the same way, $(\Delta t_{s2} - \Delta t_{s1})$ is likely to be much smaller than Δt_{s1} or Δt_{s2}. For this reason, it is the practice at the National Physical Laboratory to calibrate thermometers at the immersion at which they are intended to be used, and, for partial immersion thermometers, to measure the temperature of the air surrounding the exposed column by a standardized procedure. Nevertheless, it is clear that the thermometer should always be designed to reduce as much as possible the factor n, the number of degrees in the emergent column.

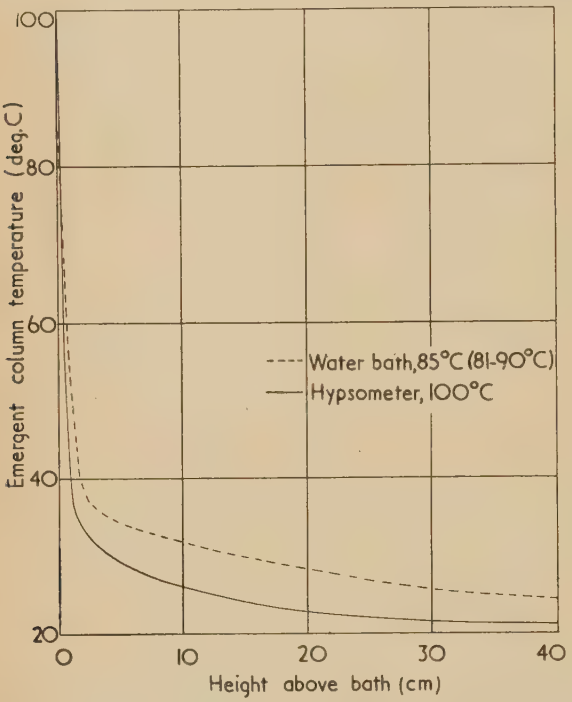

Fig. 1. Emergent column temperatures above hypsometer (100° C) and water bath at 85 ± 5° C

Experience shows that errors up to about 10% can readily occur in the measurement of either $(t - t_s)$ or $(t_{s2} - t_{s1})$, so that it is unwise to expect a higher accuracy from a partial-immersion thermometer than is given by one-tenth of the applied correction. Accepting this degree of accuracy, it is sufficient to take a mean value of 0·000 16 for α when the Celsius scale is in use, or 0·000 09 for the Fahrenheit scal The use of these values will not introduce an error exceedi 5% with any of the usual thermometric glasses. Moreov it is normally sufficient to take t as being the thermomet reading instead of the true temperature. Even in the extrem case of a temperature difference of 400 deg. C between bu and stem and an exposed column 400 deg. C long, this wou only introduce an error of 6% in the correction.

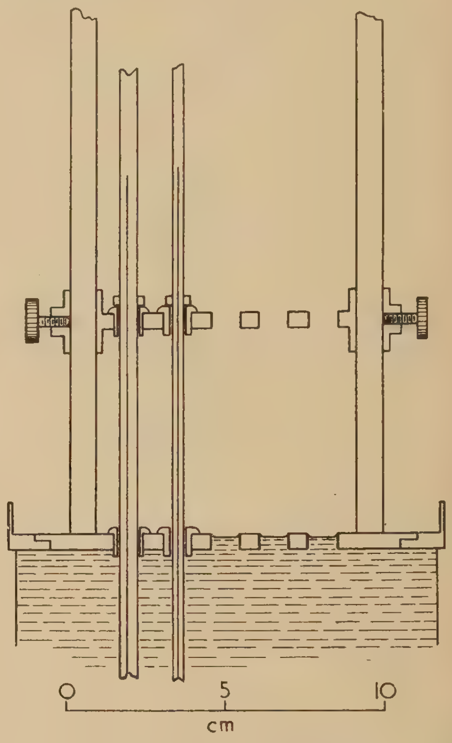

Fig. 2. Section of thermometer holder in water bath

CONDITIONS OF TEST AT THE NATIONAL PHYSICA LABORATORY

The method of mounting thermometers when they are bei tested at the National Physical Laboratory is indicated Fig. 2. The top plate of the bath, which is in dire contact with the fluid in which the comparison is mad is of brass for temperatures up to 250° C (water, stea and oil baths) and of mild or stainless steel for high temperatures (salt bath). The vertical rods and the su porting bridge are of the same metal, while the bush in the holes of the bridge are always of brass, and the thermometers loosely. The thermometers are support on the bushes by rubber rings, silicone rubber being used f the higher temperatures. In the salt bath, the thermomet are not immersed directly in the liquid, but in thin steel tub welded into the top plate. This is not bushed, and the brid carrying the bushes is always about 3 cm above it. A secon bridge is placed at a considerably greater height if lo thermometers are being used. In the water, steam and baths, the position of the lower bridge is more variable (s from 3 to 10 cm) and a second bridge is not usually necessar

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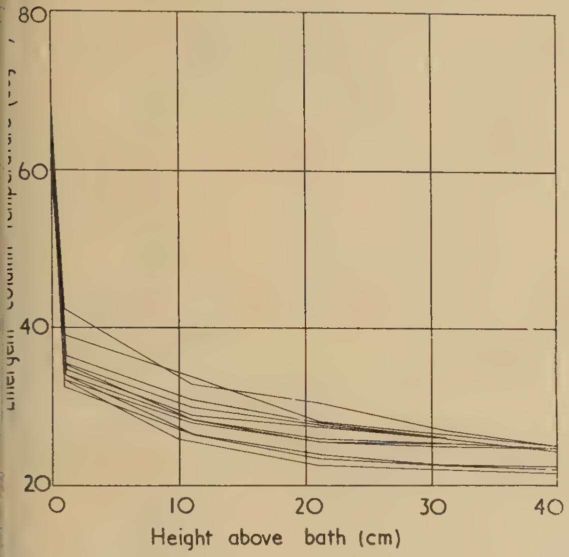
* The corrections obtained by using these constants can co veniently be applied graphically: a suitable chart, *Stem Exposu Corrections*, is published in London by H.M. Stationery Offic price 2*s*. 6*d*.

ffect of this arrangement is that the thermometer stems reely exposed to the air, and heat conduction from the to the stems by conduction along the supports is mini- d as far as possible. It is normal practice to cover the n and salt baths with one or two layers of asbestos paper, he water and oil baths are left uncovered. In each case



g. 3. Emergent column temperature above water bath at 65 ± 5° C

urface which is sensibly at the bath temperature is a disk bout 12 cm diameter.

order to establish the average values of the emergent mn temperatures of thermometers of various lengths er test at different temperatures, under normal conditions, xperiment lasting several months was carried out. An mbly of six fine-wire thermocouples was placed in turn e various testing baths in normal use. One thermocouple measured the temperature of the bath, and the other five were tied at 10 cm intervals to a glass rod of about 5 mm diameter. This was enclosed in a closely-fitting glass tube and mounted so that the lower end of the tube and the lowest junction were 1 cm above the level of the top of the bath. The couples were connected to a six-way recorder and allowed to record continuously while the bath was in use.

The observations were grouped according to the bath temperature, and the values obtained for each interval of 10 deg. C between 0° and 100° C and for each interval of 50 deg. C above 100° C were plotted together. Figs. 3 and 4 show the curves obtained for the temperature ranges 61 to 70° C and 351 to 400° C respectively. A mean curve (compare Fig. 1) was taken from each set of graphs and the emergent column temperatures (with very little smoothing) were found to vary systematically with the bath temperature. The average temperatures for columns of different lengths for each bath temperature were calculated and have been recorded in the first part of Table 1, together with an estimate of accuracy based on the spread of the curves in each group. Table 2 indicates the errors which would be introduced into the stem-exposure correction by a given error in the measurement of the mean stem temperature.

Table 2. *Errors in emergent column corrections*

Length of emergent column in deg. C	*Error in stem correction caused by 10 deg. C error in mean emergent column temperature*
10	0·02
20	0·03
50	0·08
100	0·16
200	0·32
300	0·48
400	0·64
500	0·80

The figures given for the accuracy in the last column of Table 1 are intended to be an approximate guide to all the

Table 1. *Mean temperatures of emergent columns t_s (deg. C)*

perature of bulb (° C)		5	15	25	35	45	55	65	75	85	100	125	175	225	275	325	375	425	475	*Uncertainty* Δt_s
gth of lumn posed n)	2	12	16	22	26	31	38	44	51	53	53	45	50	60	70	75	80	90	95	±20 deg. C
	4	13	17	21	24	28	34	39	43	45	42	40	50	50	60	70	75	80	80	±20
	6	14	18	20	23	27	32	37	40	41	37	40	45	50	55	65	70	70	75	±10
	8	15	18	20	23	26	31	35	38	39	35	35	40	45	55	60	65	65	70	±10
	10	16	18	20	23	25	30	34	37	38	33	35	40	45	50	55	60	65	65	± 5
	20	17	18	20	22	24	28	31	33	34	29	30	35	40	45	50	55	55	55	± 5
	30	17	19	20	22	23	26	29	31	31	26	30	35	40	40	50	50	50	50	± 5
	40	18	19	20	21	23	26	28	30	30	25	25	35	40	40	45	50	50	50	± 5
Uncertainty, Δt_s		±3 deg. C									±5 deg. C	See last column of table								—

ength of osed column (cm)	*Mean of thermometers with bulbs at*	*Mean temperatures derived from thermometers spaced along column*																	
2	2 cm	14	17	21	23	26	31	35	40	40	35	40	48	52	63	69	74	80	80
4	2, 4	15	17	21	23	25	30	34	38	38	33	36	44	48	57	64	68	73	73
6	2, 6	15	18	20	23	25	30	34	36	37	32	35	43	46	55	60	66	68	68
8	2, 8	16	18	20	23	25	29	33	36	37	31	34	42	45	53	58	63	66	66
10	2, 10	16	18	20	22	24	28	32	36	36	30	33	40	44	52	57	61	64	64
20	2, 10, 20	17	18	20	22	24	27	31	33	33	28	30	37	41	42	51	55	57	57
30	2, 10, 20, 30	17	18	20	22	23	26	29	31	31	26	28	35	38	39	47	51	52	52
40	2, 10, 20, 30, 40	18	19	20	21	23	26	28	30	30	25	25	33	36	37	43	48	50	50

measurements where the bulb temperature was greater than 100° C. The values obtained for very short columns, where the temperature gradient is steep, are clearly somewhat uncertain, but no great accuracy is required when the column is only a few degrees in length (see Table 2).

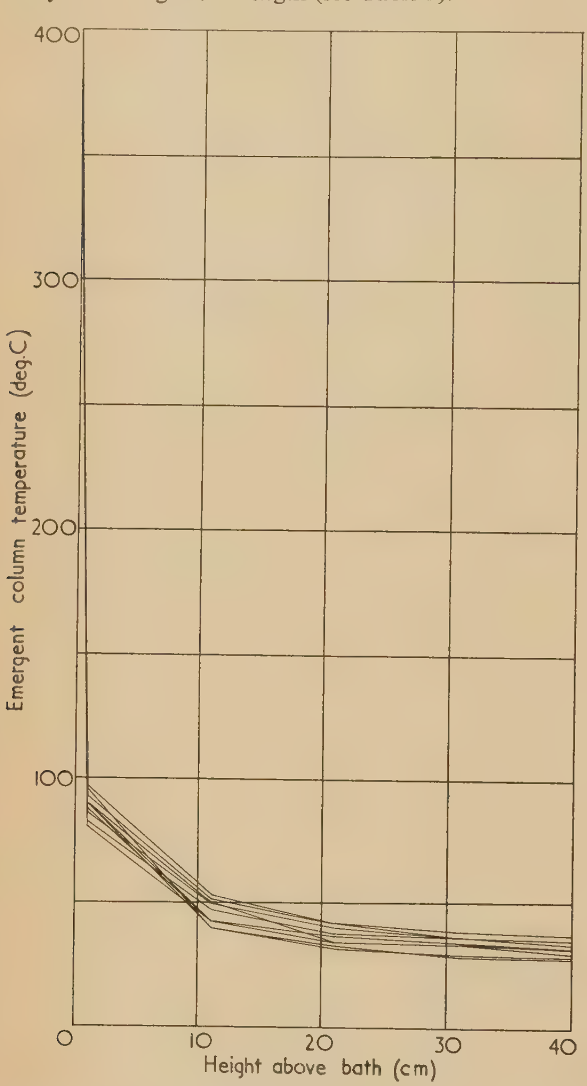


Fig. 4. Emergent column temperature above salt bath at 375 ± 25° C

PRACTICAL METHODS OF MEASURING EMERGENT COLUMN TEMPERATURES

The mean temperature of the emergent column may be measured by the use of a *fadenthermometer* (thread thermometer) or by the use of auxiliary thermometers of normal type. The *fadenthermometer* has a long bulb of about 1 mm diameter enclosed in glass of diameter similar to that of the stem. It is necessary to select one which has a bulb length equal to the length of the emergent column, so that a considerable stock of thermometers having bulbs of different lengths is required. Experience has suggested that the results obtained were not significantly more accurate than those given by suitably disposed auxiliary thermometers, and the latter were therefore adopted at the National Physical Laboratory. The second part of Table 1 gives the values of the stem temperatures deduced from the mean of the readings of a series of thermometers, one placed 2 cm above the surface of the bath and others at intervals not exceeding 10 cm along the column. Comparison with the first part of the table shows that this disposition of thermometers gives a temperature so close to that which would be obtained from a continuous measurement of temperature along the stem as not to cause an appreciable error in the correction. Owing to the steepness of the gradient near the bath, the position of the lowest thermometer is somewhat critical: if, for example, it were placed 1 cm above a bath at 450/500° C the mean temperature of a 20 cm column would appear to be about 10 deg. C higher, but, with a thermometer in which 1 mm was equivalent to 1 deg. C, this would only introduce an error of about 0·3 deg. C (Table 2).

It follows that if the best accuracy is to be obtained with a partial-immersion thermometer which has been tested at the National Physical Laboratory ($\Delta t_{s2} - \Delta t_{s1}$), should be made as small as possible by adopting a similar method of measuring the emergent column temperature.

ACKNOWLEDGEMENT

The work described in this paper was carried out as part of the research programme of the National Physical Laboratory, and is published by permission of the Director.

REFERENCE

(1) National Physical Laboratory Annual Report, 1934, pp. 29–31 (London: H.M. Stationery Office, 1935).

A vibrating condenser manometer

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The University, Birmingham

[*Paper first received* 25 *July, and in final form* 24 *October*, 1957]

The principle of the use of a vibrating capacitor to measure small displacements has been applied in an instrument to record cyclic fluctuations of air pressure. A summary is made of the results of simple experiments carried out to investigate factors influencing the amplitude of the signal generated by a vibrating capacitor. A description is given of a simple, robust instrument which has been used to measure fluctuating air pressures and reference is made to the characteristics of the instrument.

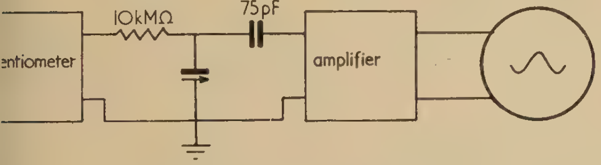
INTRODUCTION

observation of small displacements can be the basis for neasurement of a number of physical phenomena, such hermal expansion and elastic and plastic deformation. rical methods have been devised in which the displace- alters the capacitance or inductance of an element in a nced a.c. bridge, but no reference can be found to the urement of displacements by means of a vibrating citor. Published papers(1–3) describe the operation of a capacitor and its application to the measurement of act potential differences and the construction of the ting reed electrometer. In general, the ultimate sensi- has been sought in these applications and, as a result, lectronics has been complex and refined.

ie sensitivity of the signal generated by a vibrating citor to variations in the mean separation of the two rodes forming the capacitor has been applied, in con- tion with a suitable diaphragm, to the construction of nstrument for the observation of fluid pressures in the hest of a jig wash box used in coal preparation. The truction and characteristics of this vibrating capacitor ometer are described in this paper.

RELIMINARY EXPERIMENTS AND DISCUSSION

ie idea of developing a vibrating capacitor manometer nated as a result of a number of simple experiments. A ating capacitor formed from two plane circular disks, separation of which could be adjusted by means of a ometer screw, was incorporated in the circuit shown in 1. The signal generated was fed through a suitable



ig. 1. Simplified schematic diagram of the circuit used in the preliminary experiments

oling capacitance to the amplifier and displayed on a d.c. lloscope. The mean charge present on the electrodes varied by altering the settings of the d.c. potentiometer, vn connected across the vibrating capacitor through the resistance.

was found that in general the oscillogram was sinusoidal that the amplitude could be expressed empirically in is of a number of parameters namely,

$$\hat{e} = k(V_p - V_c)(r + b)/d^2 \qquad (1)$$

where

$\hat{e}$ = amplitude of the oscillogram,
k = constant dependent upon the gain of the circuit and the geometry of the capacitor,
V_p = setting of the potentiometer,
V_c = contact potential difference between the two electrodes which depends upon the nature and condition of the electrode surfaces,
r = amplitude of vibration of the one electrode,
b = constant, probably due to slight sticking in the vibration mechanism,

and

d = mean separation of the electrodes.

It can be seen that the amplitude of the oscillogram was found to be inversely proportional to the square of the mean separation of the electrodes. In practice this property would be a disadvantage where absolute measurements of displacement are to be made, but for the comparison of displacements, particularly where a wide range of displacement is involved, it would be an advantage. The value of *d* cannot be reduced to less than half the amplitude of vibration of the vibrating electrode without causing touching of the two electrodes. On the other hand, *d* cannot be increased indefinitely because the amplitude of the signal and consequently the sensitivity of the apparatus falls off rapidly with increase in *d*. A typical set of experimental values obtained with the circuit is as follows; with $(V_p - V_c)$ equal to 1 V and an amplitude of vibration of the electrode of 2 mm, a change in *d* from 0·2 to 4 mm produced a decrease in the value of $\hat{e}$ from 4×10^{-2} V to 10^{-4} V. In the actual instrument the value of V_p, the externally applied potential, is raised to over 100 V by coupling the one electrode of the vibrating capacitor to the h.t. through a resistance of the order of a few hundred megohms. This has a twofold effect; firstly it increases the signal amplitude $\hat{e}$, which is proportional to the term $(V_p - V_c)$ in equation (1), by about a hundredfold, and secondly it reduces, to a negligible value, the effect of variations (due to oxidation or to the presence of moisture), in contact potential difference V_c between the electrode.

DESCRIPTION OF THE APPARATUS

In the case of the industrial system for which this apparatus is designed the period of fluctuation of the air pressure is of the order of one or two seconds, so that it is possible to use the mains frequency of 50c/s as the vibrating frequency, thereby eliminating the necessity of constructing an oscillator. The design of the apparatus is made as simple as possible in order that the unit will be relatively robust; this is a desirable feature considering the conditions under which the apparatus is to work. The apparatus can be divided conveniently into two main units, the pressure sensing head, which includes the vibrating capacitor and the pressure diaphragm, and the detector, which includes the electronic circuits.

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* Now at British Thomson-Houston Co. Ltd., Rugby.

The pressure sensing head. The vibrating capacitor (Fig. 2) is formed from two brass disks or electrodes, of 4 cm diameter, separated by an air gap which can be adjusted, but is normally about 1·5–3·0 mm. The vibrating electrode is attached to a cylindrical Paxalin former cemented directly to the aluminium diaphragm of the head of a permanent magnet Tannoy horn loudspeaker. The other electrode is attached to the top of a stainless steel bellows unit (by Teddington Aircraft Controls Ltd.) which is connected to the air supply under investigation.

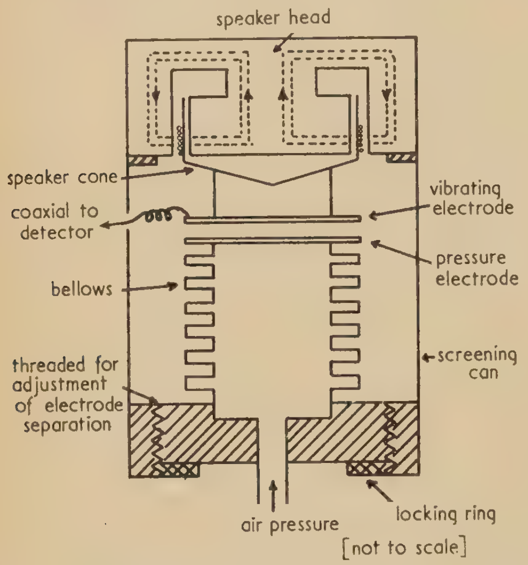
speaker head
speaker cone
coaxial to detector
vibrating electrode
pressure electrode
bellows
screening can
threaded for adjustment of electrode separation
air pressure
locking ring
[not to scale]

Fig. 2. Diagrammatic representation of the pressure sensing head

So far two bellows units have been used, one for working pressures of 0–1 lb/in.^{2} and the other for pressures of 0–3 lb/in.^{2} Each bellows unit has a maximum extension of about 1·5 mm, there being a linear relationship between bellows extension and applied pressure for each unit. Extensions of this order of magnitude used in conjunction with an initial separation (with no applied pressure) between the electrodes of about 2 mm ensure that there is a significant change in the amplitude of the signal generated by the vibrating capacitor for small pressure changes of 0·1 lb/in.^{2} or less. By using bellows of the same skirt diameter, b of different wall thickness and having a different number o convolutions, it is relatively simple to interchange bellow units and adapt the instrument to measure a different rang of pressures.

It is important that the two electrodes be parallel an coaxial for the inverse square law, indicated in equation (1 to apply for small separations. The lower electrode, which i attached to the bellows, is earthed. The upper vibratin electrode is connected by a fine, flexible wire to a coaxia cable socket and thence to the detector.

The speaker coil is actuated by a low voltage 50 c/s suppl which is brought to two terminals on the top of the pressur sensing head. The vibrator and the pressure diaphragm ar screwed into opposite ends of a large diameter brass tube so that by rotating the one section relative to the other, th mean or stationary separation of the electrodes may b adjusted to any desired value; the position of the two section can be clamped by the locking ring, fitted to the bottom of th large diameter brass tube.

The circuit. A schematic diagram of the circuit is show in Fig. 3. The signal generated by the capacitor is amplified rectified by the crystal diode full wave bridge, and appear across the output impedance chains as a low frequenc voltage fluctuation superimposed on the unidirectional 100 c/ carrier. This low frequency variation, corresponding to th pressure fluctuations at the sensing head, can be observ either as the deflexion of a d.c. milliammeter or on an oscillo scope after removal of the 100 c/s component by filtering.

At 50 c/s frequency of vibration, the impedance of th vibrating capacitor is very high. The input impedance o most ordinary commercial valves is limited, in general, a this frequency by grid current, but it was found that t EF37A, which takes relatively little grid current and a s suffers from a minimum of microphony under normal con ditions, could be used with a grid resistor as high as 20 MΩ By using, in addition, a cathode follower circuit the inpu impedance is raised to several hundred megohms, which i sufficiently high. In this way the necessity for the use o electrometer valves, with their additional complications, i eliminated.

The two disks forming the vibrating capacitor are relativel large so that, in operation, the capacitance varies from abou 15–100 pF. As a result, it is possible to separate the vibratin capacitor and, therefore, the whole sensing head from th rest of the circuit and feed the signal generated throug about 4 ft of coaxial cable, without the capacitance of th

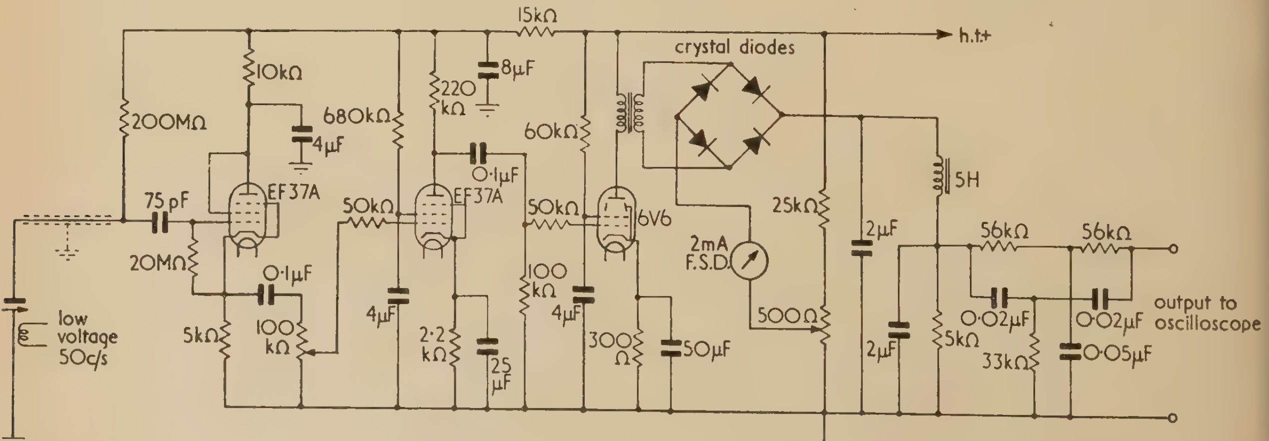
15kΩ
h.t.+
crystal diodes
10kΩ
8μF
220 kΩ
200MΩ
680kΩ
4μF
60kΩ
0·1μF
EF37A
75 pF
EF37A
50kΩ
50kΩ
6V6
25kΩ
5H
2mA F.S.D.
2μF
56kΩ
56kΩ
20MΩ
0·1μF
100 kΩ
4μF
0·02μF
0·02μF
output to oscilloscope
low voltage 50c/s
5kΩ
100 kΩ
4μF
2·2 kΩ
25 μF
300 Ω
50μF
500Ω
2μF
5kΩ
33kΩ
0·05μF

Fig. 3. Schematic diagram of the circuit used in the preliminary experiments

having much effect on the amplitude of the signal ring across the input of the cathode follower. This es the amplifier and oscilloscope to be situated on an ibration mounting, and to be clear of water. Also, if d, a number of separate sensing heads may be run in rom a single amplifier and recording unit.

e 50 c/s current for driving the capacitor is taken from a oltage tapping on the mains transformer of the power y. It is found that a suitable vibration amplitude is iced by an r.m.s. current of about 1 A, which is deter- l by the value of the series resistor.

e potentiometer situated between the first and second varies the sensitivity of the detector. This is often found l when calibrating the instrument for a particular set of urements, but once calibrated the potentiometer setting remain constant.

e four crystal diodes forming the full wave bridge rectify mplified signal and feed it to the output impedance . There it can be observed as the r.m.s. unidirectional nt on a milliammeter or fed from the 5 kΩ resistor to an oscope. The maximum r.m.s. current is kept below t 2 mA so that the maximum voltage available for the oscope is 10 V, but this is quite sufficient for the d.c. oscope used. To match the output valve of the amplifier e 5 kΩ resistor, which constitutes the bulk of the load, a former of roughly 1 to 1 ratio is used. In order to d by the oscilloscope only the relatively long period ure fluctuations occurring at the sensing head, the /s component due to the vibrating frequency must be ed-out. Most of this is done by the 5 H choke in series the 5 kΩ resistor and the shunting capacitors, and the inder is eliminated by the twin T filter in series with the loscope leads. In the case of the milliammeter, the ly deflexion due to the 100 c/s unidirectional current rimposed on the signal representing the pressure fluctua- is backed off by a steady potential, derived from the supply, placed in series with the output impedance chain. is way the full range of the meter scale can be used to rve pressure variations.

INSTRUMENT CHARACTERISTICS

or a given bellows unit, the sensitivity of the apparatus be adjusted by altering one or more of the following ables; the stationary separation of the electrodes, the of the amplifier unit and the gain of the oscilloscope lifier, so that before operation the instrument must be rated. For example, a bellows unit designed for opera- over a pressure range of 0–1 lb/in.^{2} was chosen and the onary separation of the electrodes set at 2·4 mm; the s of the amplifier unit and the oscilloscope amplifier e adjusted to suitable values and then kept constant. A sure was applied to the bellows unit and varied over the le range. The amplitude of the oscillogram was observed ther with the corresponding reading of a mercury nometer. In Fig. 4 is shown the logarithmic plot of the lied pressure against the amplitude of the oscillogram. s relationship, which represents a static calibration, may xpressed as,

$$\text{amplitude} = 0\cdot224\,(\text{pressure})^2$$

speed of response of the apparatus to changes in pressure measured by producing a sudden change in the separation he electrodes and recording the oscillogram photographi- y. For a sudden applied pressure, about 0·15 s is required ore the maximum signal amplitude is observed; the corre- nding time for a sudden decrease in pressure is about 0·35 s. The signal amplitude/time curve in each case is approximately exponential. These values of speed of response are low but may be improved by modification to the electronic circuit.

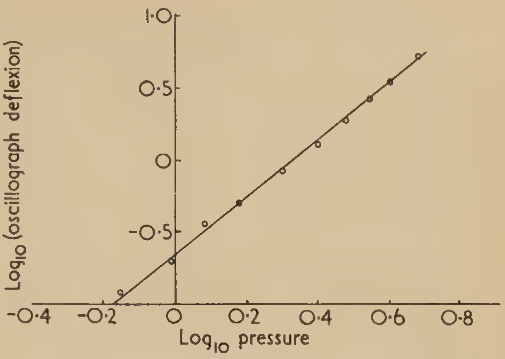

Fig. 4. Signal amplitude as a function of applied pressure

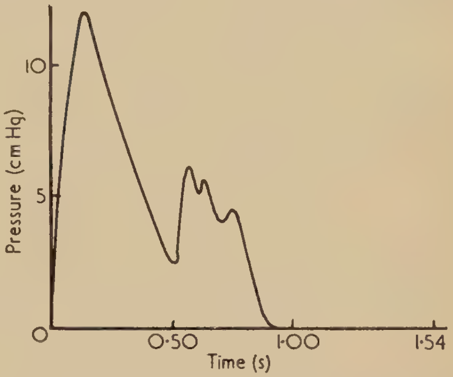

Fig. 5. Pressure/time curve for Simon Carves wash box (rotary air valves), Birch coppice colliery; period of air cycle = 1·54 s.

The apparatus has been used to determine the pressure cycles developed in the air chests of a number of jig wash boxes: one example is shown in Fig. 5.

COMMENTS

This instrument has satisfied the initial requirements. It is robust, compact and comparatively simple, but as such it does not represent the ultimate refinement. The most important fact is that the principle of using a vibrating capacitor to measure small displacements has been applied with some success. The ideal basis for the most sensitive instrument of this type would be a vibrating reed electrometer. In the case of the measurement of displacements due to fluid pressure, the pressure diaphragm would probably be the limiting factor but this might not be so in the case of displacements due to thermal expansion or to stresses in materials.

ACKNOWLEDGEMENTS

The authors wish to thank Professor Stacey G. Ward for his encouragement and advice in the development and testing of this instrument and the workshop staff of the Department of Mining who made parts of the pressure sensing head.

REFERENCES

(1) Zisman, W. A. *Rev. Sci. Instrum.*, **3**, p. 367 (1932).
(2) Rosenfeld, S., and Hoskin, W. M. *Rev. Sci. Instrum.*, **16**, p. 343 (1945).
(3) Palevsky, H., Swank, R., and Grenchik, R. *Rev. Sci. Instrum.*, **18**, p. 298 (1947).

A simple tensile testing machine for very fine wires

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[*Paper first received* 19 *August, and in final form* 22 *October*, 1957]

A simple machine is described by which stress/strain curves can be obtained for fine tungsten wires as small as 5 μ in diameter.

In recent years the development of radio receiving valves of improved performance has necessitated the manufacture of control grids made with extremely fine tungsten wire, wound to a very close pitch. It is therefore necessary to be able to measure the mechanical properties of this wire, which is usually between 5 and 10 μ in diameter. This involves the measurement of a breaking load which may be as small as 5 g, and a maximum elongation of about 2%. When an effort was made to test these wires in standard tensile test machines, very misleading results were obtained, due partly to the inertia of the moving parts and partly to the difficulty of adequately holding the very fine wire in the jaws of the machine. A special instrument was therefore devised which overcame these difficulties and facilitated the handling of this extremely fine wire. It is based on a machine devised in these laboratories some years previously by Dr. R. O. Jenkins for testing nickel wires of about 40 μ diameter.

DESCRIPTION OF THE MACHINE

The stress is applied and measured by the deflexion of a cantilever spring, while the strain is obtained from the difference between the movement of the two ends of the test wire.

The main features of the machine are shown in Fig. 1(*a*). One end of the test wire is held in a light clamp (1), which is constrained to move in a horizontal plane by two parallel spring steel strips, each 0·5 in. wide by 0·012 in. thick. These are rigidly clamped at the other end to the block (2), and, in order to increase the range of the instrument, they may also be clamped at a predetermined intermediate point.

A smooth pin, fixed horizontally to the wire clamp (1) contacts a smooth vertical pin on the pointer (3), which indicates the position of this clamp by a protractor scale reading [see also Fig. 1(*b*)].

The other end of the wire is held at (4) in a clamp which is driven by an O.B.A. threaded rod (which has a 1·0 mm pitch), either by hand or, preferably, by a slow-speed, fractional horse-power motor. The position of this clamp is accurately indicated by a vernier scale.

The pointer reading on the protractor scale gives a measure of the stress in the wire under test, while the strain is obtained from the difference between the vernier reading and the pointer reading. It is therefore necessary to calibrate the protractor scale both in terms of load on the wire and in terms of movement of the wire clamp.

In operation, when the wire breaks the pointer remains stationary, and the sudden return of the clamp (1) can be made to operate a mercury-switch to stop the drive. If only the breaking load and maximum elongation of the specimen are required, the instrument can be left to run itself, and can be driven quite fast. However, it is usually more valuable to obtain a complete stress/strain curve, and with this in view an adjustable electrical contact is fitted at (6) to indicate each complete revolution of the threaded rod by a short buzz. The position of the pointer on the protractor scale is noted at each buzz, which may conveniently be about once every fifteen seconds. With this method of operation the mercu switch is not an essential part of the machine, as the dr can be switched off by hand as soon as the wire breaks. is not difficult to measure the position of the pointer to t nearest tenth of a degree.

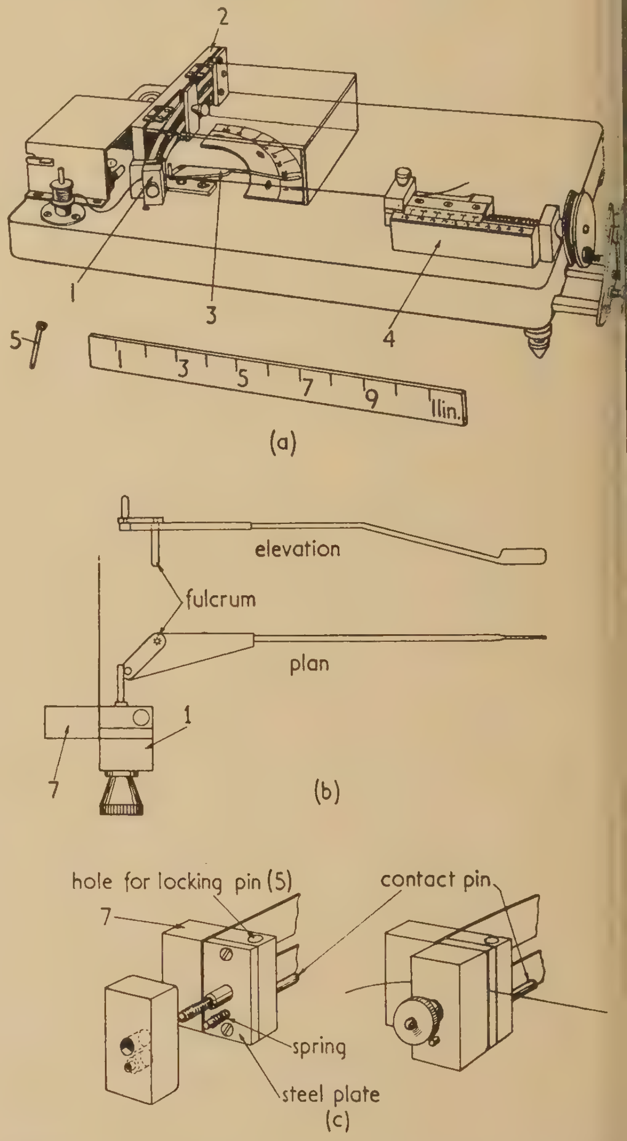

Fig. 1. (*a*) General view of test machine. (*b*) Details of pointer (3). (*c*) Details of wire clamp

It is important that the machine should be free fro vibration throughout all tests, so the fractional horse-pow motor and a starting switch should be mounted on a separa support.

The clamps [Fig. 1(*c*)] are made mainly of Dural, but t face of the main body of each is covered with a hardened olished flat steel plate. The wire is sandwiched against late by a Dural block which can readily be removed to its face to be re-lapped when necessary. The wire is d against a steel dowel-pin in the centre of the clamp, the top plate is pressed against the steel plate, in sition to a light spring pressure, by a knurled nut. A block (7) is fixed to the back of the clamp (1) to bring ntre of gravity into the plane of the supporting steel .

e calibration of the protractor scale depends on the ate maintenance of the geometric relationship between lcrum pin and the contacting pin of the pointer, so this of the pointer is made as rigid as possible. A Perspex is provided to prevent accidental damage to the pointer. the pointer moves very slowly, its inertia is not rtant. Both pins, which must be accurately parallel, oldered to a frame made of 0·010 in. sheet nickel, gthened by a steel strip $\frac{1}{16}$ in. thick. The contacting on the pointer and on the wire clamp are both highly ned, and should be kept perfectly clean. The fulcrum ests on a ball at the bottom of a plain brass bearing . deep. The needle is steel wire, 16 s.w.g., flattened at nd to reduce parallax errors. Before calibration, and g use, the machine must be accurately levelled, using evelling screws and spirit-level provided.

e load calibration of the protractor scale is obtained by ving the driver mechanism (4), clamping a light pulley e edge of the machine, and measuring the scale reading lifferent values of weights supported on a scale pan. It sirable, but not essential, that the zero of the scale should djusted to correspond to no load on the test wire. The vs fixing the scale to the base pass through slots in the to allow this adjustment to be made.

obtain the movement calibration, the driver mechanism placed and a small eyelet is fixed in each wire clamp; wo eyelets are connected together by a light, rigid rod ame length as the test wire (200 mm). The protractor ing is then calibrated directly against the vernier scale. protractor scale can be read to the nearest 0·1° quite y, and the vernier scale to the nearest 0·01 mm.

is a somewhat tedious procedure to calculate the s/strain curve from a series of protractor scale readings, n at each 1 mm movement of the vernier. However, a can conveniently be calculated from the calibration es enabling the load and percentage strain to be read tly from the protractor scale readings for all the measured ts except the last one, on fracture. When this is done only a matter of a few minutes to obtain the complete s/strain curve of a wire specimen.

OPERATION OF THE MACHINE

efore making a test, clamp (1) is locked to the base of machine by the pin (5) to avoid straining the cantilever ng; this pin is removed after the wire is fixed in clamp (1) before it is inserted into clamp (4). The electrical contact (6) is rotated until the indicator buzzes in the condition ero strain. Readings of the vernier scale are taken ally and on fracture, while the protractor scale reading ken at every buzz, and on fracture.

wo typical stress/strain curves are shown as examples in . 2 and 3; Fig. 2 refers to a good sample of 10 μ tungsten , while Fig. 3 was taken on a poor sample of 7 μ tungsten wire. It sometimes happens that the straight portion of one of these curves does not pass exactly through the origin, owing to slight errors in setting the machine or to curly wire; in this case the strain should be measured from the point at which the straight line intersects the strain axis.

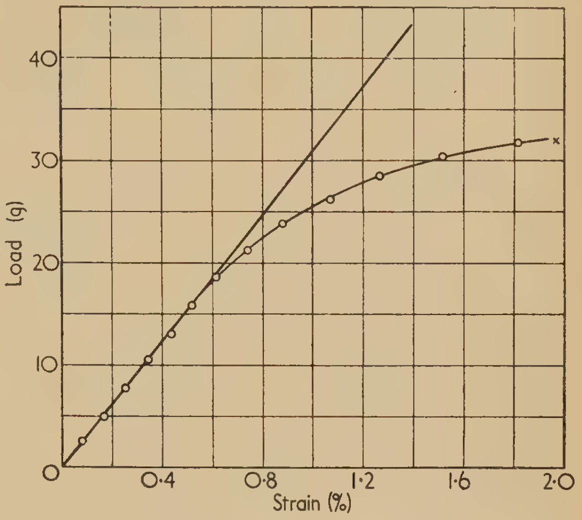

Fig. 2. Typical stress/strain curve for a good sample of tungsten wire

Wire, ref. 7/4; diameter 10 μ; weight, 0·300 mg/200 mm; breaking load, 31·8 g; total strain, 1·96%; Young's modulus, 39·0 × 10^{11} dyn/cm^2; stress, load ×1·25 × 10^9 dyn/cm^2.

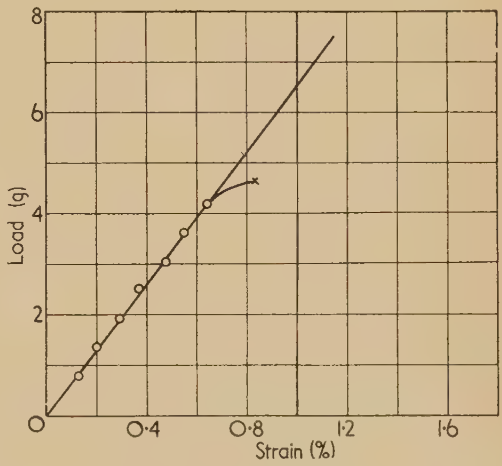

Fig. 3. Typical stress/strain curve for a poor sample of tungsten wire

Wire, ref. 7/9; diameter, 5 μ; weight, 0·076 mg/200 mm; breaking load, 4·64 g; total strain, 0·83%; Young's modulus, 32·7 × 10^{11} dyn/cm^2; stress, load ×5·0 × 10^9 dyn/cm^2.

Using the full length of the spring strips a load up to about 17 g can be measured, and with the shorter strips this is increased to about 80 g. The breaking load for 10 μ tungsten wire is usually about 30 g, so with the short spring the machine can test tungsten wires up to about 15 μ in diameter, and with the long spring it is sufficiently sensitive to be used with wires down to 5 μ diameter or even less.

Diffusion measurements by a sampling technique

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[*Paper first received* 23 *July, and in final form* 8 *October*, 1957]

An apparatus has been devised for measuring diffusion coefficients by withdrawing a small sample of the diffusion column and analysing it. The errors normally present in layer analysis methods have been minimized. Providing the volume of the sample was kept within certain limits, and the rate of withdrawal was slow, diffusion coefficients could be measured accurately. The determination of diffusion coefficients of various substances gave values which agreed excellently with known values. The method was precise to 0·4%.

Conventional diffusiometers(1, 2) cannot be used for optically opaque colloidal sols of low conductivity, such as those given by lecithin and other phosphatides, the diffusion coefficients of which are very small. Diffusiometers involving layer analysis(3, 4) are generally inaccurate owing to errors in the determination of x, the distance from the original boundary to a plane corresponding to the mean concentration of the sample. When thick layers are analysed, the concentration gradient cannot be assumed to be linear over the layer. In the method described here it is possible to analyse a small section of the diffusion column, and provided the sample is withdrawn under certain experimental conditions, x can be calculated accurately. The apparatus is capable of giving results precise to 0·4%.

The concentration at a time t and a distance x from the original boundary is given by

$$c = \frac{c_0}{2}\left(1 - \frac{2}{\sqrt{\pi}}\int_0^y e^{-y^2}dy\right) \qquad (1)$$

where c_0 is the original concentration of the solute in solution, and

$$y = x/2\sqrt{Dt} \qquad (2)$$

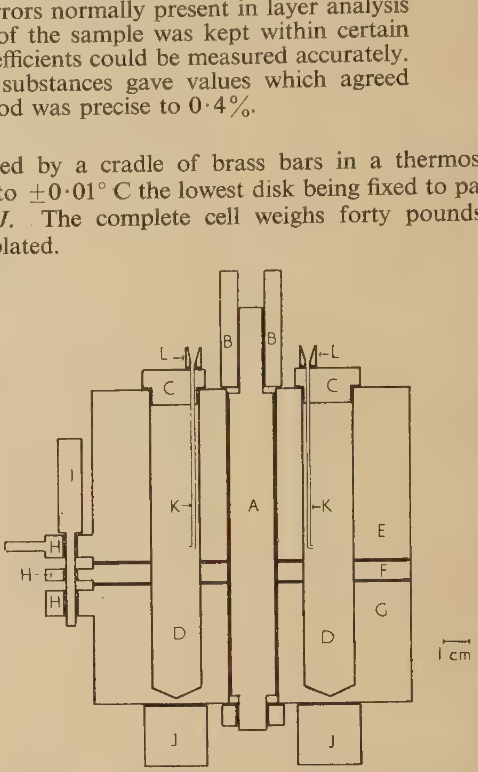
For a given value of c/c_0 there can be found the corresponding value, $\frac{\sqrt{\pi}}{2}\left(1 - \frac{2c}{c_0}\right)$, of $\int_0^y e^{-y^2}dy$, and, from tables,(5) y can be found. Hence D can be calculated from equation (2).

APPARATUS

The diffusion cell shown in the figure consists essentially of three brass disks, E, F and G, rotating on a spindle A. Three diffusion channels D are cut through the disks. The cell operates on the Neurath sliding principle.(6) The faces of the disks are machined carefully, and then accurately ground with fine emery cloth; thin layers of silicone grease on the faces prevent leakage of liquid from the cell. The seal between the disks is sufficiently good to prevent them from being pulled apart by hand.

The diffusion channels are closed at their upper ends by close-fitting brass caps C, which are clamped firmly in place. A 1 mm bore brass tube K is soldered into each cap, and passes down into the upper part of the diffusion channel. The end of the tube is turned at right angles to the direction of diffusion. Part of a syringe fitting L is soldered into the top of each cap. A microsyringe (by Burroughs Wellcome Ltd.) with a brass nose-piece is inserted into the fitting, and by withdrawing the plunger slowly and smoothly, a sample can be removed from the diffusion column.

A brass block H is set into the side of each disk, and the diffusion channels are accurately alined by passing a pin I through holes in the blocks. The clamping nut B is slackened when the disks are being rotated. The cell is supported by a cradle of brass bars in a thermostat c trolled to ±0·01° C the lowest disk being fixed to part of cradle J. The complete cell weighs forty pounds anc nickel plated.



Cross-section of diffusion cell showing two of the thre diffusion channels

MEASUREMENT OF DIFFUSION COEFFICIENT

The cell allows two alternative values of x to be us diffusion from the level of disk G gives a value of x of appro mately 1·3 cm, and diffusion from the level of disk F gi a value of x of approximately 0·5 cm. The lower parts the diffusion channels were filled with solution (either d G or disks G and F). After reaching temperature equilibri the upper disk or disks were rotated to isolate the soluti the upper part of the channel was washed out, dried, a filled with solvent or the solution into which diffusion was take place. The caps were placed in position and clamp down. When the upper liquid had come to the correct te perature, the boundary was formed by sliding the up disks slowly and smoothly round until the channels w alined. The time of diffusion was measured with an accur ex-Admiralty chronometer. The microsyringe was dri weighed, fitted into the cap of the channel to be sampl and 0·3 ml. of liquid was slowly withdrawn. The volu of the sample was determined by weighing and apply density figures. The three channels were generally sampl at intervals of two hours. The concentration of the sam was determined conductometrically for the electrolytes us and by drying and weighing for the glycine. All experime were carried out at 25° C.

Determination of x. It was assumed that the withdra sample came from a layer having the form of a disk, a t x, the distance from the original boundary to a plane responding to the mean concentration of the sample, s equal to $x_b + \frac{1}{2}x_s$, where x_b is the distance from the ginal boundary to the bottom of the opening of the sampling e. The distance x_b was found from measurements of the ckness of the disks and the lengths of the sampling tubes; is the thickness of the withdrawn disk of liquid as cal- ated by dividing the volume of the sample by the cross- tional area of the diffusion channel. The withdrawn er was very thin (0·1 cm) and the concentration gradient s assumed to be linear over the layer.

Materials. All materials were of Anala R quality (by British ug Houses Ltd.). Water was distilled in an all-glass still, n passed down a column of mixed strong ion exchangers. e specific resistance of the water was 3–4 MΩ cm^{-1}.

RESULTS AND DISCUSSION

The effects of the rate of sample withdrawal and the volume hdrawn on the diffusion coefficient of 0·2 M/l. potassium oride into water are shown in Tables 1 and 2. (D has been ınd(7) to be $1 \cdot 851 \times 10^{-5}$ cm^2 s^{-1}.)

Table 1. *The effect of the volume removed on D*

(Time occupied in withdrawal = 100 s)

Volume removed (ml.)	0·2863	0·3062	0·3218	0·3492	0·4027	0·4601	0·5022
$D \times 10^5$	1·850	1·851	1·848	1·858	1·876	1·894	1·918

Table 2. *The effect of the time occupied in withdrawal on D*

(Volume withdrawn = 0·300 ml.)

Withdrawal time (s)	5	20	40	60	70	100	150
$D \times 10^5$	1·423	1·610	1·776	1·850	1·852	1·850	1·850

Table 3. *Diffusion coefficients of various substances*

Substance	$\bar{c}$*	Δc	$D \times 10^5$	$D \times 10^5$ *(literature)*
Potassium chloride	0·1000	0·2000	1·851, 1·850 1·847, 1·852 1·847 1·852, 1·852 1·848, 1·853†	1·851(7)
	0·3300	0·2000	1·840	1·840(7)
Sodium chloride	0·01482	0·01487	1·540	1·542(8)
Ammonium sulphate	0·05252	0·04191	0·801	0·803(10)
Glycine	0·003339	0·006679	1·054	1·058(9)

* $\bar{c}$ = mean concentration of upper and lower solutions in M/l. c = concentration difference between solutions in M/l.

† The short x value of about 0·5 cm was used for these two results. The long value of approximately 1·3 cm was used through- ıt the rest of the experiments.

For volumes between 0·28 and 0·32 ml., the correct result r D was obtained; for volumes larger than 0·32 ml., D as too large; presumably in this case the values obtained r x were too large. For times less than 60 s, D was too ıall; in this case it seems likely that the diffusion column as greatly disturbed.

A full test of the apparatus on various substances was ade obeying these conditions. The results are shown in ble 3.

Three values of D are obtained in each experiment, and ese were used to give a single value corrected for any viation of the initial boundary from infinite sharpness by Longsworth's method,(1) D being plotted against $1/t$ and an extrapolation made to $1/t = 0$. Only small values of Δt, between 0 and 20 s, were obtained when diffusion was allowed to proceed for 10–20 hours. Values of D obtained agreed well with those from other methods. The standard deviation of the nine values for $\bar{c} = 0 \cdot 1$ M/l. potassium chloride was 0·002345, and the fiducial limits at a probability of 0·99 were $1 \cdot 850 \pm 0 \cdot 0078$. The method is capable of giving accurate results, and would be useful for the study of the diffusion of mixtures.

ACKNOWLEDGEMENTS

The author would like to thank Dr. L. Saunders for useful discussions, and Mr. P. C. Barden for building the apparatus.

REFERENCES

(1) LONGSWORTH. *J. Amer. Chem. Soc.*, **69**, p. 2510 (1947).
(2) HARNED and NUTTALL. *J. Amer. Chem. Soc.*, **69**, p. 736 (1947).
(3) COHEN and BRUINS. *Z. Phys. Chem.*, **103**, p. 349 (1923).
(4) BOURDILLON. *J. Gen. Physiol.*, **24**, p. 459 (1940).
(5) ALEXANDER and JOHNSON. *Colloid Science*, p. 236 (London: Oxford University Press, 1950).
(6) NEURATH. *Science*, **93**, p. 431 (1941).
(7) GOSTING. *J. Amer. Chem. Soc.*, **72**, p. 4418 (1950).
(8) HARNED and HILDRETH. *J. Amer. Chem. Soc.*, **73**, p. 650 (1951).
(9) LYONS and THOMAS. *J. Amer. Chem. Soc.*, **72**, p. 4506 (1950).
(10) WISHAW and STOKES. *J. Amer. Chem. Soc.*, **76**, p. 2065 (1954).

An airflow interrupter for respiratory work

By L. E. Mount, M.D., Agricultural Research Council, Institute of Animal Physiology, Babraham, Cambridge

[*Paper received* 12 *September*, 1957]

A respiratory airflow interrupter designed to give information on lung alveolar pressure is described. A slotted rotor moving with a uniform speed of 24 rev/min inside a slotted sleeve provides 192 interruptions per minute; the sudden pressure change at the mouth on interruption of the airflow is due to equilibration of pressure throughout the lung airways and is determined mainly by alveolar pressure.

The use of rapidly occurring interruptions of airflow as a means of obtaining information on pressure-flow relations in the lungs has been discussed by Otis and Proctor(1) and Mead and Whittenberger.(2) When the airway is blocked suddenly at the mouth during respiratory airflow, equilibration of air pressure takes place throughout the lungs and airways and results in a quick change in pressure at the mouth. The amplitude of this pressure change is determined mainly by the alveolar pressure obtaining at the moment of interruption, and provides a measure of the pressure difference between mouth and alveoli. A slower rate of change of pressure follows the equilibration, the direction of this continuing change depending on the phase of respiration in which the interruption occurs. These pressure variations are shown in Fig. 1 for one inspiration and one expiration. An interruption of airflow during inspiration results in a negative-going pressure change at the mouth, since alveolar pressure is lower than mouth pressure during respiratory inflow. The first part of the change, shown between arrows for interruptions, is rapid, and gives the magnitude of equilibration pressure which is a measure of alveolar press During expiration the pressure changes are similar in f to those during inspiration, but are in the positive direc since alveolar pressure is now higher than mouth press so that equilibration pressure is above mouth pressure. the end of each interruption, flow is resumed and the mo pressure changes to the level obtaining before interruption

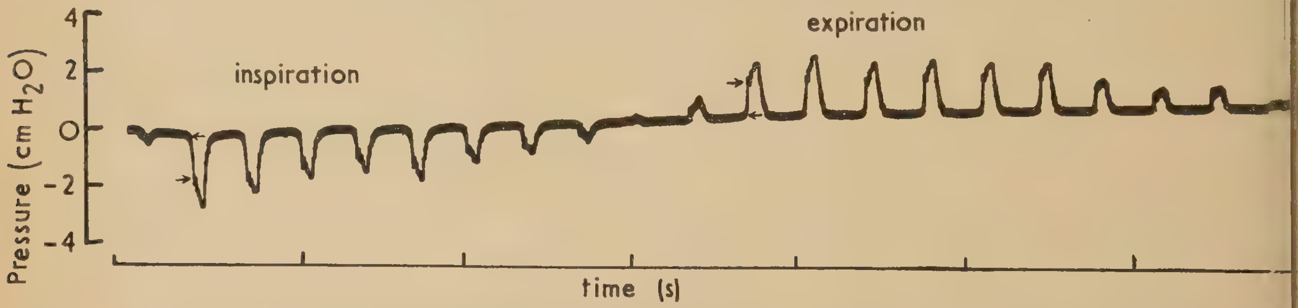
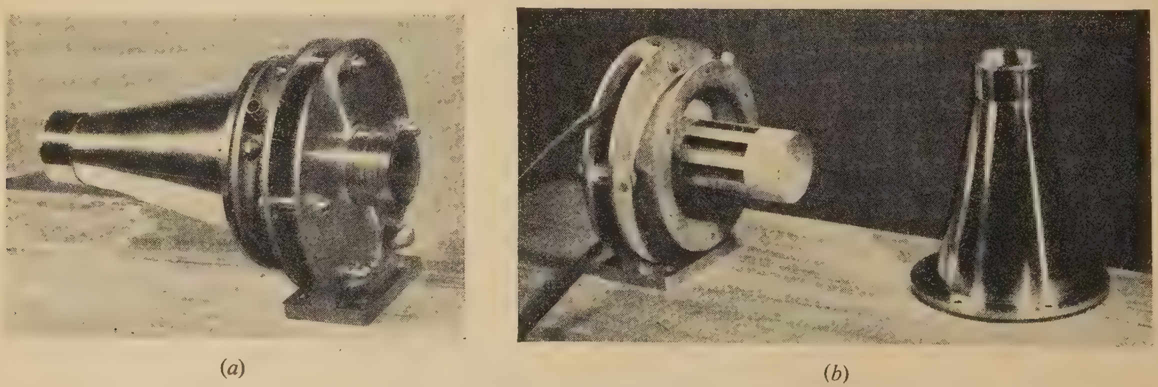


Fig. 1. Recording of mouth pressure during interruptions of respiratory airflow in a normal human subject. Th effects of interruptions during one inspiration and one expiration are shown; the arrows indicate the extent of sudden pressure change due to equilibration in the lung airways on interruption. Each division on the time scal represents 1 s

Rotor speed: 24 rev/min

To bring about the sudden occlusion of an aperture wh when open, would be large enough to allow relatively impeded respiratory airflow, would require a rapidly mov airtight shutter, which, if discontinuous in its motion, mi set up vibrations obscuring the pressure record. It desired to make a shutter device operating at uniform velo to overcome this difficulty; Fig. 2 shows the instrument, Fig. 3 the details of construction. A phosphor-bro cylinder *C* rotates at constant speed inside the stationary s



(*a*) (*b*)

Fig. 2. Airflow interrupter

(*a*) Assembled; (*b*) cone detached.

inder *D*; both cylinders are closed at the end inside the ne, and both have eight regularly spaced longitudinal slots in the walls, although the slots in the rotor are narrower n those in the steel sleeve. When the rotor slots (0·080 in. le) are opposite the sleeve slots (0·242 in. wide) the airway patent; as the rotor slots pass behind the edges of the eve slots they are all cut off simultaneously, and airflow is cked until rotor and sleeve slots are again coincident. ly a small angular movement is required to block all the ts simultaneously, so that occlusion is rapid even though or speed is relatively low.

The steel sleeve is secured to a circular brass plate [Fig.)], which is drilled centrally to allow the phosphor-bronze rotor to pass through it and on through a second similar brass plate, held rigidly coaxially at a fixed distance from the first; a short section of steel sleeve is mounted on the far side of the second brass plate and acts as an airtight bearing for the rotor, the end of which may be seen in Fig. 2(*a*). In the space between the two circular brass plates [Fig. 3(*a*)] a pulley wheel is mounted on the rotor and a belt drive taken to a motor [Fig. 2(*b*)]. A brass and copper cone, shown in position in Fig. 2(*a*) and detached in Fig. 2(*b*), makes an airtight seal with an annular projection from the first circular brass plate, and covers the slots in the sleeve and rotor; the slots are situated only in the lengths of sleeve and rotor within the length of the cone, as shown in Fig. 3, *C* and *D*. The apparatus is thus designed for the leakproof passage of gas through it, and, when used in conjunction with volume or flow recorders and a quickly responding manometer (e.g. capacitance type), allows pressure-flow curves to be constructed for the lung airways.

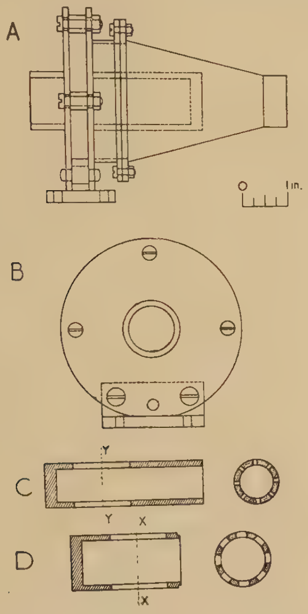


Fig. 3. Constructional details of airflow interrupter

4, diagrammatic side view; *B*, diagrammatic view of end listant from cone; *C*, phosphor-bronze rotor, with transverse ection through *Y* — *Y* shown on right; *D*, steel sleeve, with transverse section *X* — *X* shown on right.

In practice, it has been found that a speed in the region of 24 rev/min is suitable, giving 192 interruptions per minute; each interruption cycle then occupies 0·31 s, and during approximately 0·1 s of this time interval the airflow is blocked. Very little hindrance to respiration is felt at this speed except at the highest airflows, and in the normal subject 0·1 s is several times greater than the time required for pressure equilibration in the lungs, as shown in Fig. 1. At faster speeds, oscillations at the resonant frequency of the pressure-recording apparatus appear on the trace; at lower speeds, the interruptions are not completed rapidly enough for accurate measurement of equilibration pressure in the lungs.

ACKNOWLEDGEMENTS

The author is indebted to Mr. C. C. Ingrey and Mr. A. Legge of the Institute of Animal Physiology for the construction of the interrupter.

REFERENCES

(1) Otis, A. B., and Proctor, D. F. *Amer. J. Physiol.*, **152**, pp. 106–112 (1948).
(2) Mead, J., and Whittenberger, J. L. *J. appl. Physiol.*, **6**, pp. 408–16 (1954).

Anti-reflexion coatings for indium antimonide and other semi-conductor filters

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[*Paper received* 18 *October*, 1957]

Several important infra-red filters use semi-conductors with refractive indices near 4 (e.g. Ge, Pbs, InSb), which have high reflexion losses. Lead chloride is shown to be a good material for "blooming" these semi-conductors. Such "blooming" more than doubles the transmission of an InSb filter from 10–13·5 μ.

ere are many infra-red applications where it is essential to e a filter giving positive rejection of all short-wave radiation t transmitting the required longer wavelengths. The rious semi-conducting materials which are used for such rposes have excellent rejection characteristics and sharp nsitions from absorbing to non-absorbing regions. How- er, in the latter region the characteristic high refractive indices result in high reflexion losses, so efficient anti-reflecting layers are essential.

Three of the most important semi-conductors, germanium, lead sulphide and indium antimonide, which transmit radiation beyond 1·8, 3·0 and 7·3 μ respectively, all have long-wave refractive indices within 2 or 3% of 4·0. The peak transmittance, at normal incidence, of an interface between materials of refractive index n_0 and n_p when bloomed with a quarter wave film of index n is given by

$$T = 1 - \left(\frac{n_0 n_p - n^2}{n_0 n_p + n^2}\right)^2$$

For the above materials this becomes

$$T = 1 - \left(\frac{4 - n^2}{4 + n^2}\right)^2$$

so that ideally the blooming layers should have an index of 2·0.

Materials which have been used previously (namely zinc sulphide and selenium) are too highly refracting to be ideal. We have successfully used lead chloride, which as shown below, has a calculated peak transmittance which is nearly perfect.

Calculated transmittance of slab with λ/4 blooming layer on both sides

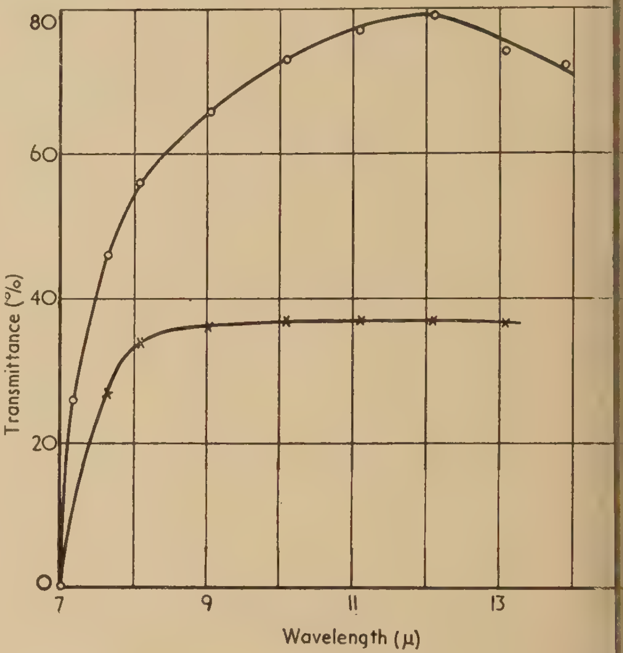
(Slab index = 4·0 at λ)

Index of blooming layers	*Peak transmittance at λ*
2·0 (Ideal)	100%
1·9 ($PbCl_2$)	99%
2·37 (ZnS)	94%
2·46 (Se)	90%

The lead chloride used was in the form of broken crystals and was evaporated from a molybdenum boat. The film maintained its optical quality quite adequately as the thickness was increased to an optical thickness of λ/4 at 12 μ. During evaporation the layer thickness was monitored by reflected radiation of wavelength near 2 μ, at which wavelength 5 quarter wavelengths were deposited.

The figure shows the results obtained with an indium antimonide filter, designed to transmit the whole of the 8–14 μ atmospheric window. Over most of this region the transmission of the indium antimonide is more than doubled by the blooming layers. The rejection at 6·5 μ is of the order of 3000 : 1 and is vastly greater for shorter wavelengths. From the transmittance before blooming we may deduce that there is some absorption in the indium antimonide crystal at 12 μ since from the known refractive index of 3·93*—including multiple reflexions—the transmittance should be 47% at this wavelength. By considering the first and second transmitted beams the absorption for a single traverse of the crystal may be calculated to a good approximation as 19%. The peak transmittance of 79% thus indicates that the anti-reflecting layers are showing almost optimum performance.

The crystal (of the order of 90 μ thick and 1 cm in diam was prepared from a 1 mm slice by grinding and polis one surface. It was then firmly stuck down on a glass using molten shellac as a glue, and the other surface ground to the desired thickness and polished. Finally crystal was removed from its substrate by dissolving shellac in warm alcohol. Further work on crystal prepara has shown that this technique may be used to pro



Transmittance of bloomed indium antimonide filter

×, indium antimonide crystal approximately 90 μ thick.
○, indium antimonide crystal with blooming layer.

specimens less than 50 μ thick. At such a thickness indium antimonide filter should show a peak transmitta slightly above 90% but rejection at 6·5 μ would fal about 150 : 1.

A severe test of an indium antimonide filter has been m by Dr. R. M. Goody in a solar grating spectrometer, w the filter replaces the fore-prism. At 10·8 μ he finds $<$ 0·2% of the received energy was scattered radiation f other wavelengths.

ACKNOWLEDGEMENTS

Acknowledgement is due to Dr. R. M. Goody of Impe College Meteorological Department for the above meas ment and to Miss D. M. Webber for skilful preparatio the crystals.

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* Moss, T. S., Smith, S. D., and Hawkins, T. D. F. *Proc. Phys. Soc. B*, **70**, p. 776 (1957).

A feedback controlled Pirani gauge

By J. H. Leck, M.Eng., A.M.I.E.E., A.Inst.P., Department of Electrical Engineering, The University of Liverpool

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This paper describes a simple feedback circuit for the Pirani gauge in which the power supply to the Wheatstone bridge is adjusted automatically so as to keep the wire temperature approximately constant over a wide range of pressure changes. This is achieved by supplying the power from a d.c. amplifier which is itself controlled by changes in wire temperature, a small fall in temperature serving to increase the power output from the amplifier. A transistor is employed as the input stage of the amplifier. The comparatively large zero drifts in the transistor d.c. amplifier due to temperature changes are no particular disadvantage in this application as the Pirani gauge signal is also dependent upon ambient temperature.

the various methods of control for the Pirani gauge, the constant temperature, the constant voltage and the ıstant current Wheatstone bridges, the constant tempera- e gives the greatest useful pressure range. In this tech- ue a thin hot wire in the vacuum system is made one arm a Wheatstone bridge, the current through the bridge ving both to heat the wire and to indicate balance. After initial setting balance is maintained at all pressures by justing the bridge current. (The wire is constructed of itinum or tungsten or some other metal with a large nperature coefficient of resistance so that the bridge balance critically dependent upon the wire temperature. Any drop temperature can be restored by increasing the current and erefore the heat generated in the wire.) Provided the lecular mean free path is large compared with the wire ımeter, the heat conducted from the wire is directly pro- rtional to the gas pressure. This gives a relation between t wire current I and pressure p of the form $I^2 - I_0^2 = Kp$, being the current at zero pressure and K a constant involv- the gas conductivity and the wire resistance.

In its simple form—where the bridge current is readjusted er every pressure change—this technique suffers the obvious sadvantages of difficulty in following rapid changes in essure and in automatic recording. Further, the hot wire n be damaged by overheating if the bridge current is not duced immediately the pressure falls. These difficulties may overcome by using an automatic control unit to adjust bridge current, so keeping the bridge balanced under all nditions of pressure change. The obvious way of doing is is to form a closed-loop feedback circuit, making the idge out-of-balance and supply currents the input and tput respectively of the same amplifier. An increase in t-of-balance current produces an increase in the supply rrent and therefore always tends to restore balance.

The chief requirement of the amplifier is small zero drift, a change in amplifier zero level cannot be distinguished om an input signal. Because the simple d.c. amplifier has elatively poor zero stability, an audio-frequency system is nerally preferred.(1) The magnetic amplifier is, however, a eful alternative, providing a simple system with a high bility, but with a limited power output in a single unit.(2) e circuit described in this paper is a further alternative to . working having the simplicity of the magnetic amplifier thout its limited power output. The design is based on a o-stage power amplifier with a germanium transistor ming the input stage. The transistor is particularly suit- le for this application as its input impedance is approxi- tely matched to the output impedance of the Wheatstone dge. The chief disadvantage of transistor d.c. amplifiers— ir temperature instability—is of no particular importance the Pirani element is itself sensitive to ambient temperature variations. In fact the drifts in the two units are in opposite directions and approximately equal so that some measure of compensation is achieved.

ELECTRONIC CONTROL CIRCUIT

The complete circuit diagram is shown in Fig. 1. The bridge out-of-balance voltage is applied directly to the input of the amplifier, the first stage being the transistor effectively in grounded base operation ($R_3 \gg R_2$). An increase in pressure, by reducing the temperature of the hot wire (R_w), increases the input current to the transistor (I_e) and therefore the grid potential of the triode valve. ($I_c \simeq I_e$ in grounded base operation.) This obviously increases the bridge current and hence the wire temperature, so tending to restore balance. Perfect temperature stability is, of course, achieved only by making the amplifier gain infinite. The phase advance network shown in Fig. 1 is included to improve stability. Without phase advance the comparatively long gauge time constant combined with the high amplifier gain tends to

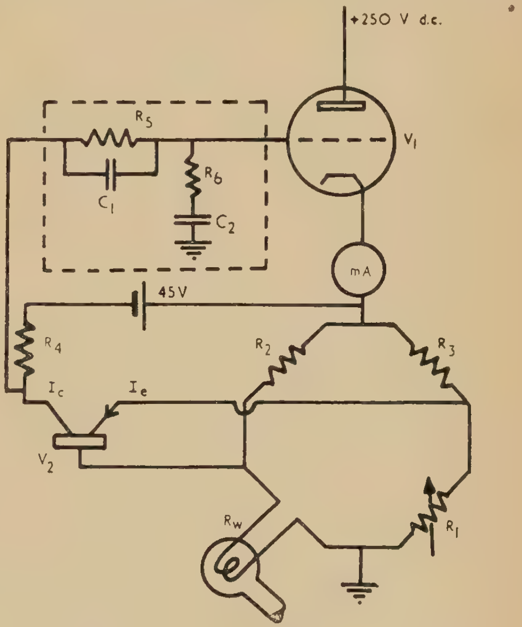


Fig. 1. Diagram of automatic temperature control circuit

V_1, K.T. 66 triode connected; V_2, p.n.p. transistor, Mullard OC73; R_w, tungsten wire Pirani gauge element, 0·001 in. diameter, approximately 60 in. long; R_1, 1500 Ω; R_2, 100 Ω; R_3, 600 Ω; R_4, 1 MΩ; R_5, 10 MΩ; R_6, 100 kΩ; C_1, C_2, 0·5 μF.

allow oscillations to build up at a frequency of the order of 1 c/s.

Using the component values shown in Fig. 1 and with R_1 adjusted to give a bridge current of 20 mA at zero pressure (corresponding to a wire temperature of 100° C) $I_e \simeq I_c \simeq 20\ \mu$A and the grid bias is −25 V. The variation of both amplifier output and input current as a function of pressure are shown in Fig. 2 for this particular setting. The amplifier gain is seen to be 4000 over the whole useful range. The true constant temperature characteristic (obtained by manual operation) is also shown in Fig. 2 emphasizing how closely automatic operation approaches the ideal.

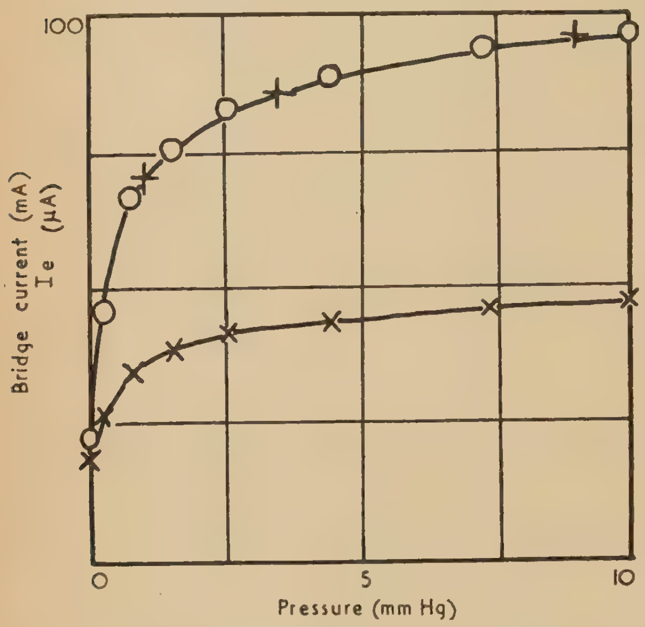


Fig. 2. Wheatstone bridge supply and out-of-balance currents as a function of the gas pressure (air)

○, bridge supply current (mA); +, bridge supply current (mA) for true constant temperature operation (obtained by manual control); ×, bridge out-of-balance current (μA).

Because this device operates as a high gain amplifier with 100% negative feedback, the characteristics are virtually independent of the amplifier characteristics. For example, a reduction of battery voltage from 45 to 25 V, or, in h.t. supply, from 250 to 170 V, changes the bridge current by only 1 mA, i.e. the equivalent of a pressure change of 10 μ at low pressure (below 100 μ) or 150 μ at a pressure of 5 mm of mercury. On the other hand, the characteristics are dependent upon the transistor temperature. An increase in the junction temperature increases the collector leakage current (I_{co}) which is indistinguishable from a change in input signal. Direct measurement has shown that a change in this temperature from 25 to 26° C increases the amplifier output current by +0·1 mA (equivalent to 1 μ at pressure). The hot wire itself is affected in the oppo sense by ambient temperature change, the factor increa with pressure from −0·04 mA/° C at zero pressure approximately −0·1 mA/° C at 1 mm of mercury above.(3) Thus the transistor compensation is correct high pressure, but unfortunately too great at low pressure

DISCUSSION

This unit has the obvious advantage of simplicity over a.c. control circuits. This is particularly true as no stabil tion is required for either the main supply (250 V 100 m or the 45 V battery. However, if a battery is conside undesirable this supply can be replaced by a small n reference valve with only a small increase in complex This valve must be connected with a suitable series resista between the cathode and a negative supply line of appro mately 200 V. The advantages of the transistor over magnetic amplifier are of cost and increased gain, coup with the fact that the maximum available power supplied the Wheatstone bridge can be raised comparatively ea and without loss of gain by using two or more triode val in parallel operation. A further feature of this design is ease with which a robust electromagnetic relay can be add in series with the bridge. It can be adjusted to "trip" at pre-determined current and therefore pressure.

The temperature compensation afforded by the trans at high pressure is purely fortuitous. The position is ideal since the actual compensation achieved must depen a certain extent upon the collector leakage current of actual unit. The temperature instability introduced by transistor can be reduced by an order of magnitude by us two transistors in the input stage to balance out the collec leakage current.

ACKNOWLEDGEMENT

The help given by Professor Craggs in preparing t paper and his encouragement throughout the work is gra fully acknowledged.

REFERENCES

(1) Spangenberg, K. R. *Vacuum Tubes*, Chap. 21 (N York: McGraw Hill Book Co. Inc., 1948).
von Ubisch, H. *Ark. Mat. Astron. Fys.*, **36A**, No (1949); *Nature* [*London*], **161**, p. 927 (1948); *Appl. S Research*, **A2**, p. 403 (1951).
Litting, C. N. W. *J. Sci. Instrum.*, **32**, p. 91 (1955).
(2) Leck, J. H., and Martin, C. S. *Rev. Sci. Instrum.*, p. 119 (1957).
Hamilton, A. R. *Rev. Sci. Instrum.*, **28**, p. 693 (195
(3) Leck, J. H. *Pressure Measurement in Vacuum Syste* Chap. 2, p. 48 (London: The Institute of Physics, 195

graphite resistance furnace for physicochemical studies up to 2200° C

By J. D. Mackenzie, Ph.D.,* and J. O'M. Bockris, D.Sc.,† Department of Chemistry, Imperial College, London

[*Note received* 4 *November*, 1957]

or physicochemical measurements which require an curately controllable and relatively large constant hot ne, the conventional tungsten or molybdenum wire-wound sistance furnace is satisfactory up to about 1800° C, the per limit being imposed by the refractory tubing used. apid variations of temperature are restricted by the thermal ock to the refractory, generally alumina. The graphite sistance furnace shown in Fig. 1 has been developed for udies up to 2200° C and permits rapid heating or cooling.

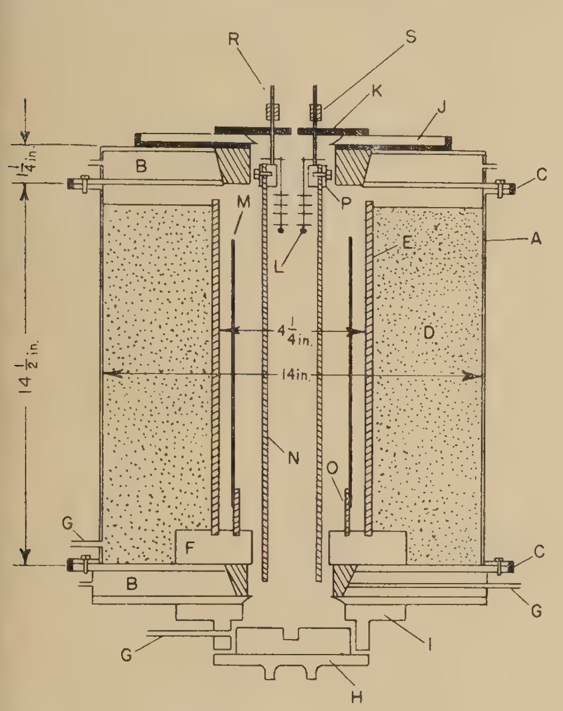
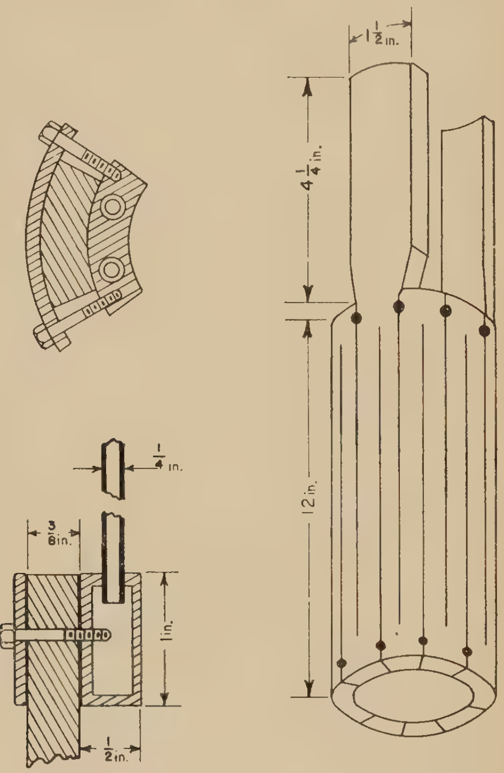


Fig. 1. General view of high-temperature furnace

A, $\frac{1}{16}$ in. brass barrel; *B*, water-cooled ends; *C*, Plasticine seals; *D*, lamp black packing; *E*, graphite tube; *F*, alumina brick platform; *G*, gas inlets; *H*, mobile chuck; *I*, mild steel housing; *J*, brass plates; *K*, asbestos cover; *L*, horizontal radiation shields; *M*, vertical radiation shields; *N*, slit graphite heater element; *O*, alumina ring; *P*, water-cooled clamps; *R*, $\frac{1}{4}$ in. copper tubes; *S*, brass bar clamps.

The cylindrical brass body *A* was water-cooled at both ds *B* and rendered airtight by the seals at *C*. The lamp ack packing *D* was held in place by the graphite tube *E* sting on the alumina brick platform *F* which reduced heat sses by conduction. The bottom was sealed off by the jection of graphite grease into the narrow annular space tween *H* and *I* and the furnace interior kept in an inert or reducing atmosphere by gases which were admitted at *G* and permitted to escape through the small central opening at the top of the apparatus. To reduce radiation losses, a tubular vertical radiation shield *M*, made of 0·004 in. thick molybdenum, was placed between the heater element *N* and the tube *E*. The heater element was held in position by the water-cooled clamps *P* and suspended *via* the copper tubes *R* which allowed passage of both water and current. Power was supplied by a 10 kVA autotransformer with a continuously adjustable output of 0–230 V, 0–40 A, fed into a fixed-ratio transformer having a maximum output of 30 V and 300 A. At 6 kVA the temperature attained was 2000° C; and at 10 kVA, 2200° C. A constant hot zone ($\pm 10^\circ$ C) of 8 cm was maintained at this upper temperature.

Details of the slit graphite heater element and the water-cooled clamps are shown in Figs. 2(*a*) and (*b*). The former, based on a design by Burton and Mayorcas,(1) was made from a graphite tube of internal diameter $2\frac{1}{4}$ in. and thickness $\frac{3}{8}$ in. The slits were cut longitudinally and the sections insulated from one another by small lengths of $\frac{1}{16}$ in. diameter alumina tubes inserted in the ends. Sixteen slits were cut, eight on each side of the arms to give two resistances in parallel. The length of each section was 12 in. and the total resistance of the element about 0·1 Ω. Satisfactory measurements of the viscosity of liquid silica in a concentric cylinder apparatus at temperatures in excess of 2000° C by the adaptation of this furnace have been reported elsewhere.(2)



(b) (a)

Fig. 2. Details of graphite heater element and water-cooled clamps

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ACKNOWLEDGEMENTS

The authors are grateful to Dr. J. A. Kitchener for valuable advice, and to the British Iron and Steel Research Association for financial support.

REFERENCES

(1) Burton, E. J., and Mayorcas, R. *J. Iron and Steel Inst.*, **168**, p. 151 (1951).
(2) Bockris, J. O'M., Mackenzie, J. D., and Kitchener, J. A. *Trans Faraday Soc.*, **51**, p. 1734 (1955).

An X-ray collimator for single-crystal goniometers

By E. N. Maslen, B.Sc., Chemical Crystallography Laboratory, University of Oxford

[*Note received* 16 *August*, 1957]

A collimator has been constructed for use in single-crystal X-ray work consisting basically of a lead glass capillary, and this has been found to be generally superior to most of the metal collimators at present available.

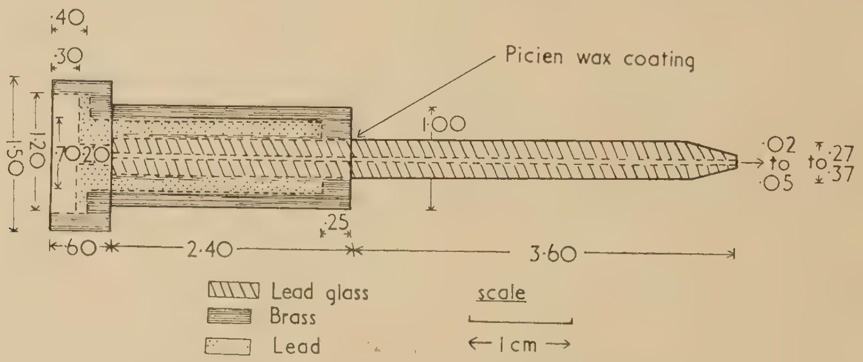

Fig. 1. Section through capillary collimator
The dimensions are given in centimetres.

The use of lead glass capillaries for collimation of an X-ray beam is by no means new, and they have found application in many fields, especially in the study of metals and other polycrystalline materials. Early workers observed that they had the property of reinforcing the X-ray beam by total reflexion at the inner surface of the glass, and Hirsch,* in a review of the information published on capillary collimation in fine beam work, derived formulae for calculating the gain in intensity at the specimen in terms of the internal diameter of the tubing and the critical angle of reflexion of X-rays from the glass. In the single-crystal field use was made of capillary collimators prior to 1939 by Prof. W. T. Astbury, of the University of Leeds, and his co-workers, and several developments have been made since that time. The present model, however, as well as being simple to construct and readily adaptable to all standard instruments, has many advantages over those available previously. It has a nearly uniform beam with a small angle of divergence for its aperture, and it eliminates entirely the scattering which frequently occurs at the edges of screens and apertures in metal collimators. It should thus be particularly useful where minimum scattering and low beam divergence are advantageous.

The capillaries were manufactured by Plowden and Thompson Ltd., Stourbridge, who prepared a batch of glass containing 34% lead oxide, coloured black to facilitate optical alinement of the capillaries. These were drawn outside diameter 0·27–0·37 cm and bore 0·02–0·05 cm. best of the tubing was then cut to appropriate lengths, of which was inserted in a metal sheath prepared as follo A brass rod, 1·40 cm in diameter, was drilled to suita depths with 1·20 and 0·70 cm bits, and then partly fi with lead. It was then reversed on the lathe, and a slightly larger in diameter than the capillary was dri almost to the top of the lead insert, and the outside of rod was turned down accurately to 1·00 cm for 2·40 cm its length. The hole drilled for the capillary was then c pleted with an 0·2 cm drill. This design (Fig. 1) ensu that there was no possibility of leakage of X-rays betw the glass and the lead, or between the lead and the brass.

When the capillary was inserted, it was given a thin coa of Picien wax, so that by heating the metal sheath wit small flame the wax softened sufficiently for small correcti to be made to the position of the capillary. The collima was then mounted on the goniometer on which it was inten for use, and, using the optical equipment on this instrum the capillary was accurately alined and centred.

The performance of one of the poorer capillaries was t compared with that of two of the more conventional bra aperture type collimators to gauge the success likely to attained without any great care in the selection of the mater for the component parts of the collimator. Strips of pho graphic paper were drawn through the beams at kno distances from the mouths of the collimators (Fig. 2). Fr

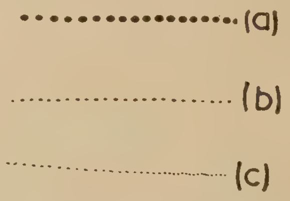

Fig. 2. Traces obtained by passing a film strip through the beam at 2·0 cm from the end of each collimator in turn

(*a*) Brass collimator, bore 0·050 cm.
(*b*) Brass collimator, bore 0·032 cm.
(*c*) Glass capillary collimator.

these films the beam diameters at various distances w measured, giving the results tabulated below.

It was also noticed by examining the film blackeni under a microscope that the beam from the capillary co mator was much more nearly constant across its width th those of the brass collimators.

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* Hirsch, P. B. *X-ray diffraction by polycrystalline materials*, pp. 284–6 (London: The Institute of Physics, 1955).

Comparison of collimators

be size (cm) and type	*Beam diameter at 2 cm*	*4 cm*	*Beam divergence / tube diameter*	*Efficiency*
	(cm)	*(cm)*	*(rad/cm)*	*(r/cm$_2$)*
ss aperture, ore diam. 0·050	0·106	0·150	0·42	$k \times 3{\cdot}9$
ss aperture, ore diam. 0·032	0·054	0·070	0·25	$k \times 4{\cdot}7$
ss capillary, val bore ·016 × 0·024	0·022 to 0·032	0·027 to 0·040	0·17	$k \times 5{\cdot}9$

A lead insulin crystal, mounted in a thin-walled soft glass illary with a little of its mother liquor, was then photo-phed for the same time with each of the collimators in n (Fig. 3). The X-ray reflexions recorded on each film ere roughly equal in intensity, but the intensity of the back-ound and general scattering was considerably lower in the otograph taken with the capillary collimator.

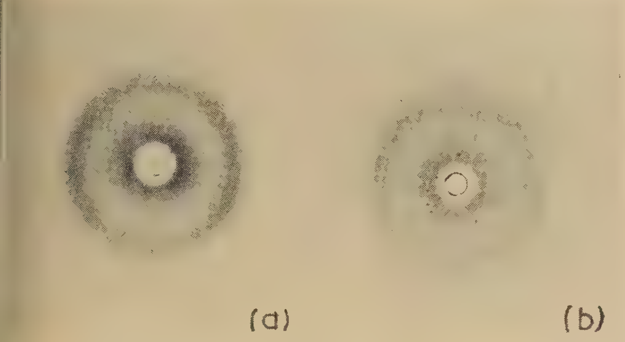


Fig. 3. Oscillation photographs of lead insulin taken with (*a*) Brass collimator, bore 0·032 cm, and (*b*) Glass capillary collimator, showing reduction in the scattering around the central spot, with the capillary collimator

Thanks are due to Dr. Dorothy Hodgkin and Dr. H. M. well for their advice and assistance, and to Mr. F. Welch o provided the mechanical skill necessary for this work.

he reduction of misalinement voltage in Hall measurements

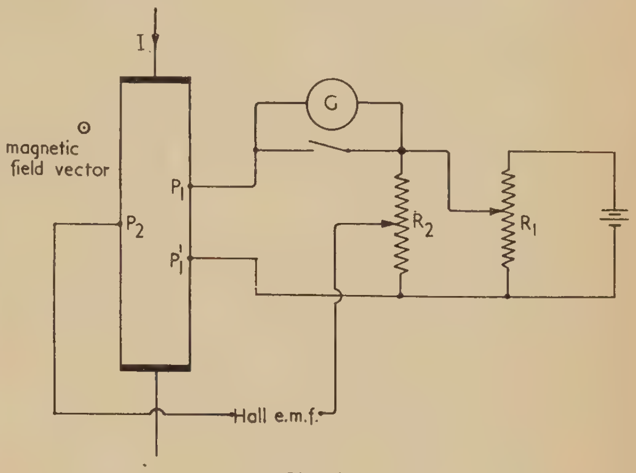
By L. W. Davies, B.Sc., D.Phil., A.Inst.P., Commonwealth Scientific and Industrial Research Organization, Radiophysics Laboratory, Sydney, Australia

[*Note received* 27 *August*, 1957]

e Hall voltage of conducting solids may be measured on a ctangular sample: contacts are placed on opposite faces, that the line joining the contacts is normal both to the agnetic field and to the current. It is often difficult to adjust e position of the contacts sufficiently accurately that the tential difference between the probes in the absence of a agnetic field (the misalinement voltage) is much less than e Hall voltage.

The problem is generally solved with the aid of two contacts ich as P_1, P_1' in the figure), bridged by an adjustable voltage vider; the resistance of this divider must be much greater an the resistance of the sample between the contacts, in order to minimize the disturbance of the current flow in the sample. The divider is then adjusted to give a negligible misalignment voltage. A disadvantage of this method is the reduction in sensitivity which follows the increase in resistance of the measuring circuit due to the insertion of the voltage divider.

With the technique to be described here, which makes use of the circuit shown in the figure, it is possible to reduce the misalinement voltage to a negligible value without reduction in the sensitivity of the Hall voltage measurement. In addition, there is no flow of current through the Hall contacts, so that the current distribution in the sample is unaffected by the measurement.



Circuit

With the sliding contact to R_2 open-circuited, the potential difference between the contacts P_1, P_1', which arises from the current I in the sample, may be backed off using a potentiometer R_1 and galvanometer G as null indicator. No current is then drawn from P_1 or P_1'. The misalinement voltage, as measured with a potentiometer between P_2 and the sliding contact to R_2, may be made arbitrarily small by adjustment of the sliding conatct. But in addition the resistance of R_2 may be chosen sufficiently small that it does not significantly affect the measuring sensitivity.

The technique described above has been used in Hall measurements on evaporated films of germanium, where the misalinement voltage was readily reduced to a value less than 5% of the measured Hall voltage without loss of measuring sensitivity and with no disturbance to the distribution of current in the thin film.

An insulated vacuum lead-in using an O-ring

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[*Note received* 10 *September*, 1957]

The insulated vacuum lead-in described here incorporates a number of desirable features which are not simultaneously present in those recently reported.(1–4) The lead-in is especially suitable for low-voltage, high-current use and has the following advantages:

(*a*) The lead-in is easily demountable.

(*b*) A minimum area of neoprene (or rubber) is exposed to the vacuum as the seal is made with an O-ring. O-rings are readily available and are easily replaced if deterioration occurs.

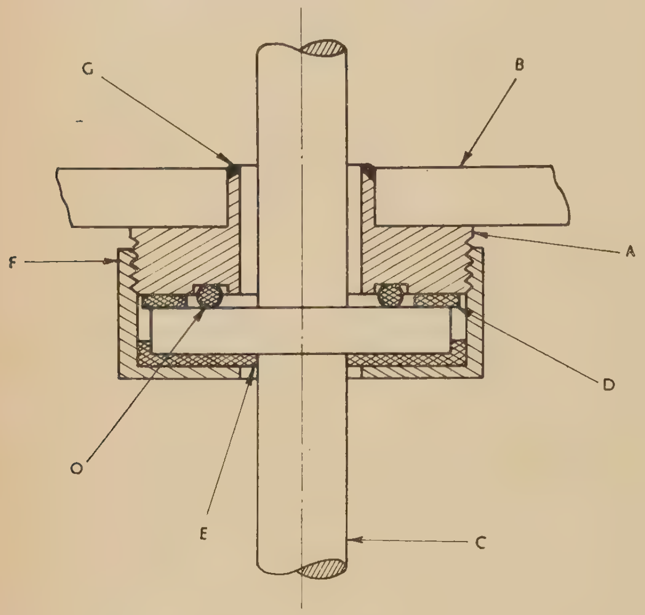
(*c*) Sealing washers and screw threads are not used within the vacuum system. They usually contain "dead" spaces which considerably increase the pump-down time of the system.

(*d*) The lead-in provides a rigid support for associated equipment within the vacuum system, e.g. a carbon heater.

(*e*) No shield is necessary when the seal is used in a vacuum evaporation plant, as the insulator—the O-ring—is not in the line of sight from the main vacuum chamber.

(*f*) The lead-in may be internally water-cooled if necessary without modification of the O-ring seal itself.

(*g*) A limited amount of rotation is possible through such a seal.



Insulated vacuum lead-in

A, brass O-ring seat; *B*, inside wall of the vacuum chamber; *C*, copper lead-in; *D* and *E*, Bakelite or plexiglass insulating ring; *F*, knurled locking ring; *G*, vacuum-right soldered joint between *A* and *B*; *O*, O-ring.

The figure shows the type of seal described. The brass O-ring seat *A* fits into a circular hole in the wall of the vacuum chamber *B* and is kept in position by the permanent, vacuum-tight soldered joint at *G*. This eliminates screw threads and sealing washers from the vacuum system—see point (*c*). The O-ring is located in a shallow groove in *A* which is typically 0·05 in. deep for a 0·125 in. thick O-ring. The compression of the O-ring is limited to the recommended value by the insulating ring *D*. Insulator *E* centres the lead *C* within the locking ring *F*.

In an alternative design, which gives the maximum insulation possible with a given O-ring, the O-ring groove is eliminated. To hold the O-ring in position under vacuum a loosely-fitting Teflon$^{(5,6)}$ ring must now be included.

The breakdown voltage of the seal varies with pressure. The grooveless type of seal was found to have a minimum breakdown voltage of 360 at a pressure of approximately 0·1 mm of mercury when a 0·130 in. thick O-ring was used. $\frac{1}{2}$ in. diameter leads *C* have been used in seals of both types to supply 325 A to a vacuum furnace used for the growth of silicon single crystals.

REFERENCES

(1) Herne, H. *J. Sci. Instrum.*, **23**, p. 244 (1946).
(2) Moore, M. J. *J. Sci. Instrum.*, **27**, p. 231 (1950).
(3) Smith, J. R. *J. Sci. Instrum.*, **29**, p. 131 (1952).
(4) Fuschillo, N. *J. Sci. Instrum.*, **33**, p. 402 (1956).
(5) Hogg, B. G., and Duckworth, H. E. *Rev. Sci. Instr* **10**, p. 331 (1948).
(6) Jensen, N. *J. Appl. Phys.*, **27**, p. 1460 (1956).

An electron gun alinement and mounting technique

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[*Note received* 16 *September*, 1957]

In our laboratory the need arose for a demountable elect gun for experimental purposes. The electron gun in this c was for use in a klystron and had to be attached to the cop resonator body and alined accurately with respect to drift tube through the resonators. The arrangements u consisted of three ceramic rods, each with a pellet of cop attached to one end which was accurately turned and threac These three rods were then screwed into the copper resona body. The electrodes which constituted the electron gun w made in the form of disks, each with three holes drilled coincide with the positions of the ceramic rods. The g was assembled simply by sliding the electrodes on to ceramic rods with ceramic or glass washers giving suita spacing. A clip then held this assembly in position. T three holes in the resonator body were alined with resp to the drift tube by a master jig. This same jig control positions of the three holes in the electrode disks. The r were made by electro-depositing the copper and then turn and threading this with respect to the accurately grou ceramic rod. The final rod was of very high accuracy. cone turned on the copper mated with another in the ho in the resonator body and assured that the rods sto vertically when screwed into position. A small slot in copper pellet prevented the trapping of gas.

Electron guns mounted in this manner proved hig accurate and were also repairable. Although the fi

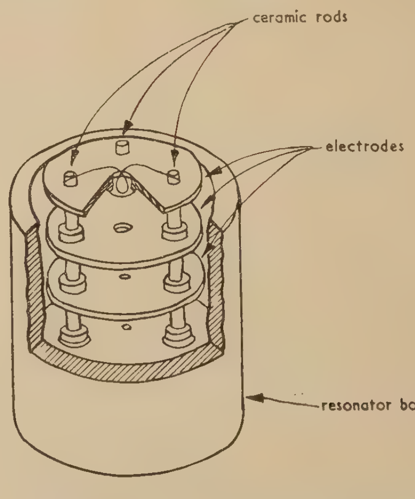

Fig. 1. Diagram of gun electrodes mounted above resonator

uracy was not measured it is believed to be within 01 in. in electrode concentricity and within 0·0002 in. in trode separation. Fig. 1 shows an electron gun mounted ove a klystron resonant system. One of the ceramic rods h its attached copper pellet is shown in Fig. 2.

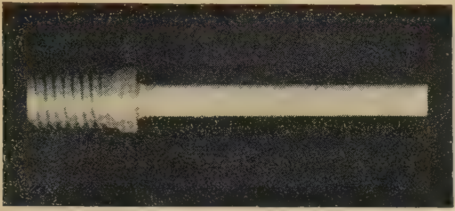

Fig. 2. One of the ceramic rods with attached copper pellet

This technique was brought under control by the efforts of . G. F. Montgomery, and was improved by Mr. M. F. J. lkins and his staff. Help and encouragement from Mr. W. Pybus is gratefully acknowledged. This note is blished by permission of the Chief Scientist, Australian partment of Supply.

The closure of high pressure vessels: a hydraulic high-torque torque wrench*

By E. Whalley, B.Sc., A.R.C.S., Ph.D., D.I.C., A. Lavergne, and R. Goton, Ignénieur, E.S.C.I.L., D. de l'U. (Lyon), Division of Applied Chemistry, National Research Council, Ottawa, Canada

[*Note received* 3 *September*, 1957]

There are two main groups of closures for high pressure ssels. These are:

(*a*) the self-sealing closures which require only a small rce to close them and are made tighter by the applied essures, and

(*b*) the non-self sealing closures. These require the sealing rfaces to be forced together with a force at least equal to at which will be exerted on the closures by the pressure. hen the pressure becomes high enough the force squeezing gether the sealed surfaces is counter-balanced by the essure, and the seal leaks. The maximum pressure obtainle without leaks is thus a function of the force applied to e sealing surfaces, and so of the torque applied to the htening nut. Consequently the seal acts as a safety valve.

The safety valve thus obtained is often very valuable if e pressure becomes dangerously high. For example, if a emical reaction which is being carried out in a closed system comes explosive the pressure in the reaction vessel may come very high before there has been time enough for aterial to leave the vessel by the normal exit and burst the fety-disc. If the seal of the vessel opens at a pressure fficiently below the bursting pressure the danger due to the plosion is reduced.

The higher the pressure and the larger the vessel the more fficult it is to provide the closing force necessary for such a al to be used. This force can be somewhat reduced by ing a partly self-sealing closure such as a lens ring, or a ne ring with an included angle of 40 or 50° between the ces, but it is still frequently rather high. For example a ssel which we use up to 1500 b ($b \equiv bar \equiv 10^6$ dyn cm^{-2}) d have tested to 2300 b has an internal diameter of 3 in. and is closed by a cone ring with an included angle of 40° between the sealing faces. The head, cone ring, and body are tightened by means of a gland nut with a 4 in. diameter thread with 12 threads per inch. A torque of 6000 ft.lb was required to tighten the vessel so that it would just open at its test pressure of 2300 b. If the seal is to be used as a safety valve this torque must be applied in a reproducible manner. The common practice of hitting a wrench with a sledge is not adequate. We have therefore devised, and describe in this note, a hydraulically operated torque wrench which can be easily and cheaply made and is suitable for an almost unlimited range of torques. It is not, of course, restricted to use with pressure vessels.

The wrench was made in order to tighten nuts with a hexagon head and a similar hexagon was machined on the top of the body of the vessel. Two wrenches of the shape shown in the diagram were cut from 1 in. boiler plate steel, and short pieces were welded at the end of the arm of one of them to ensure that the ends were in line. The hexagons on the wrenches were cut with a diagonal inclined at an angle of 15° to the arm of the wrench so that by reversing and interchanging the wrenches they could be put in a suitable position for use with the jack no matter what was the relative positions of the hexagons on the body and the head. It is necessary to leave a gap, in which the wrench can be rotated, between the nut and the hexagon which is on the body. The jack which is used to force apart the ends of the wrenches is a 4 ton hydraulic jack (by Blackhawk Mfg. Co.). The force exerted by the jack is measured by measuring the oil pressure with a Bourdon gauge. The torque exerted on the nut is easily calculated from the area of the piston of the jack, the pressure of the oil, and the distance between the jack and the axis of the nut. Any required torque is readily reproduced, and the opening pressure of the vessel can be reproduced to about 150 b in 2300 b. Wrenches of a given size can be used for smaller hexagons by inserting appropriate spacers between the wrench and the nut.

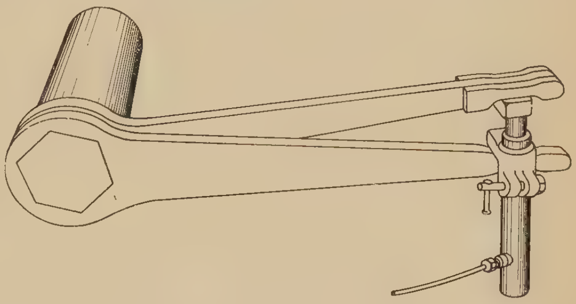

Diagram of torque wrench

That the safety valve obtained in this way is effective is shown by the results of an explosion which we had in this laboratory. The explosion occurred in both the vessel and its connecting tubing. The tubing, which bursts at 5000 b or higher, ruptured, and a Bourdon tube was overstrained by an amount which suggests that it was subjected to about 5500 b. Although the explosion also occurred within a vessel of 1 litre capacity no detectable change within ±0·0005 in. of the internal dimensions occurred. The yield pressure of the vessel was about 2500 b so we infer that the seal opened before the pressure had risen much above this value.

A similar principle has been used previously* to close vessels intended to hold steam at pressure up to 55 b. The ends of the wrenches were forced apart by means of a screw thread and no provision was made for measuring the torque.

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*N.R.C. No. 4553.

* Osborne, N. S., Stimson, H. F., and Fiock, E. F. *J. Res. Nat. Bureau Standards*, **5**, p. 411 (1930).

Removal of signal fluctuations in a photoelectric polarimeter

By A. R. Downie, M.A., D.Phil., Courtaulds Limited, Maidenhead, Berks

[*Note received* 18 *September*, 1957]

Malcolm and Elliott* have described a simple photoelectric polarimeter in which the analyser is rocked manually between two positions a few degrees apart and on opposite sides of the extinction position, and the polarizer is rotated by means of a micrometer screw until the two positions of the analyser correspond to equal transmission. The transmitted light falls on a photomultiplier tube whose output is observed without amplification on a Cambridge Spot Galvanometer. With an instrument of this type, variations in signal occurring in a time of the order of seconds limit the precision of the measurements and make observations very tedious. Provided that care has been taken to remove birefringent particles from the solution being studied, the chief causes of these variations are fluctuations in (*a*) the intensity of the incident light and (*b*) the voltage applied to the photomultiplier cell. The former is particularly troublesome when the polarimeter is being used in conjunction with a monochromator to make dispersion measurements, for it is then usually necessary to focus a mercury arc of high surface brightness and small size on the slit of the monochromator. As a result, even if the total energy emitted remains constant slight wandering of the arc can cause considerable variation in the amount of light reaching the polarimeter.

The effect of both types of fluctuations could be almost entirely eliminated by means of a simple feed-back device. A suitable beam-splitter is placed immediately inside the entrance pinhole of the polarimeter, so that a small part of the beam falls on a second photomultiplier cell of the same type as that in the polarimeter, and run from the same power supply. The voltage supplied, and hence the output, can be controlled by means of a potentiometer, The signal from the monitor cell is fed to the galvanometer and opposes that from the polarimeter. Its size is adjusted until, when the polarimeter is balanced, there is no deflexion at either analyser position. Under these conditions variations in the power supply and intensity of illumination affect the polarimeter and backing-off signals equally and their effect is thus eliminated.

It was not possible easily to adapt our instrument to incorporate this ideal form of compensator, but we have affected a good deal of improvement by a simpler device using a barrier-layer photo-voltaic cell, the output from which can be suitably attenuated with a decade resistance box. As this cell is not very sensitive to ultra violet radiation, it is necessary to sample the undispersed beam; this is done by placing a piece of microscope cover glass at 45° to the beam immediately inside the entrance slit of the monochromator and allowing the reflected radiation to fall on the barrier-layer cell. Compensation for variations in light intensity will in this case be complete only if the intensities of the various spectral lines fluctuate to the same extent. This is likely to be very nearly the case once the lamp has reached a steady temperature. Moreover, the different parts of the slit do not contribute to polarimeter and backing-off signa exactly the same way. Nevertheless, the lamp noise has reduced by an order of magnitude. Changes in signal to variations in the photomultiplier power supply are of course affected, but these can be reduced by using a stabilized supply, and in our instrument are much less seri than those due to the lamp.

My thanks are due to Dr. A. Elliott for suggesting the of a barrier-layer cell.

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* Malcolm, B. R., and Elliott, A. *J. Sci. Instrum.*, **34**, p. 48 (1957).

A variable ratio, tape-coupled, recording microdensitomet

By P. C. Russell, M.Sc., and J. E. Wilson, M.A
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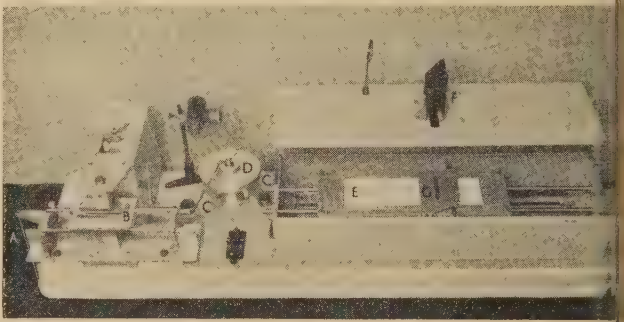
[*Note received* 16 *October*, 1957]

The microdensitometer to be described has been built used in this department for the study of X-ray spectrogra It was designed and developed as an accurate and inexpe instrument. The expense in the conventional microdens meter is due to the precision required in the gears conne the recording material to the negative under examination

The present machine can best be described by referenc the accompanying photograph. The photometer part of apparatus is of conventional design; it can be seen that recording emulsion is used in a plane form and is moun on the carriage *E*. The choice of a plane carriage was de mined by the need to use glass slides for the recordings paper has a known tendency to shrink and become distort



Variable ratio recording microdensitometer

The light from the photometer is fed to a galvanome (out of the picture on the extreme right), and the light be from this in the form of a vertical line is received by prism *F* and directed on to the slit *G*. Thus a spot of li falls on to the emulsion, its position at right angles to movement of the carriage indicating the density of blackening on the examined negative. The examined negat is similarly moved on a carriage *B*; the link between the t carriages is by means of the steel tapes *C* and the differen pulley *D*. The steel tapes are tensioned by means of weig hanging from *A* and *I*. The cord *I* passes round an axle which acts as a capstan, and is driven by an external mot

It will be readily appreciated that the precision gear been replaced by the differential pulley, which, made in t parts, enables the magnification of the instrument to easily changed. This microdensitometer, which was bu with normal workshop facilities, has proved a most relia and satisfactorily accurate instrument over the past two yea It will be noted that the instrument does not allow measu ments to be made and a subsidiary comparator is necessa for the measurement of the densitometer curves.

Correspondence

method for measuring transistor current gain at radio frequencies

e first step in a direct determination of the complex internal rent gain of a transistor, and hence of its internal cut-off quency, is the measurement of the near-short-circuit ernal current gain α. One method for doing this, which s been used elsewhere$^{(1)}$ and in this laboratory,$^{(2)}$ is to ect a radio-frequency signal into the emitter circuit and n determine the ratio of the voltages developed across two ual small resistances in the collector and emitter circuits. ese voltages are proportional to the collector and emitter rents respectively. A convenient way of comparing these ltages is to amplify them in a twin-channel high-frequency eiver, the amplified signals being converted to intermediate quency before being fed to the X and Y plates of an cilloscope; analysis of the elliptical trace which results, lds the complex external current gain. Useful results have en obtained in this way up to 105 Mc/s.$^{(2)}$ Because such ecialized equipment will not be available in all laboratories, alternative method for comparing the collector and emitter ltages, which should be capable of development for use at quencies up to tens of megacycles, is suggested. The ethod is illustrated schematically in Fig. 1.

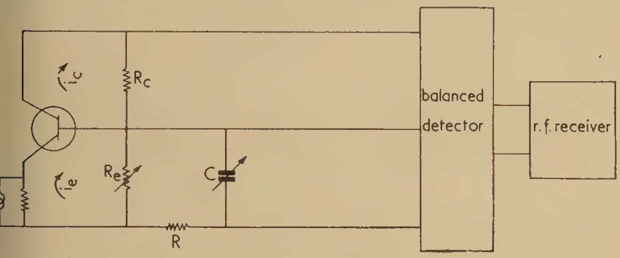


Fig. 1. Schematic circuit for measurement of $\alpha \equiv i_c/i_e$

The voltage developed across a fixed small resistance R_c bout 50 Ω) in the collector circuit is fed to one-half of a lanced detector, the input impedance of which must be uch greater than R_c. The resistance R_e in the emitter rcuit is made variable: the voltage developed across it is d *via* the potentiometer comprised of R and C to the other lf of the balanced dectector. Here $|R + 1/j\omega C| \gg R_e$; and R_e are adjusted so that a null is indicated by the radio-equency receiver following the balanced detector. The ode of operation may be understood by reference to Fig. 2. ne solid curve represents a typical variation with frequency the external short-circuit current gain $\alpha = i_c/i_e$ of a ffusion-type transistor.$^{(2)}$ The dashed semicircles represent, on the same scale, the variation with frequency of the ratio $R_e/R_c(1 + j\omega CR)$ for different values of R_e. At a given frequency, adjustment of C and R_e will ensure that a semicircle will be generated which intersects the transistor curve at the appropriate point P in Fig. 2, so that there is equality between the current transmission of the transistor and the voltage transmission of the CR potentiometer. Under these circumstances the current gain is given by

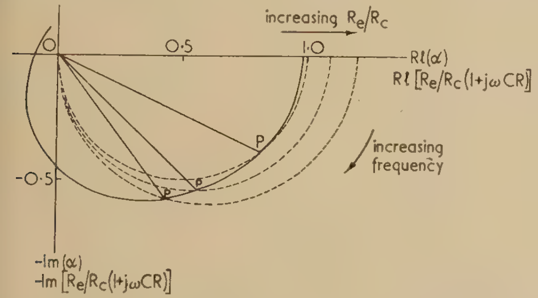


Fig. 2. Comparison of transistor current gain locus (solid curve) and semicircular transmission loci of the CR potentiometer

$$\alpha(\omega) = i_c/i_e = R_e/R_c(1 + j\omega CR).$$

The co-ordinates of the point of intersection may readily be found in terms of R_e/R_c, C, R and ω. It may be seen that for measurements up to the 3 dB-down frequency of the current gain, which is considered to be the useful frequency range of the apparatus, the variation of R_e will not be large. By feeding the emitter from a constant-current source it can be arranged that variation of R_e does not affect the emitter and collector currents.

The system has been tested in practice up to a frequency of 50 Mc/s using a transistor, the external short-circuit current gain locus of which had been found to be very closely semicircular,$^{(2)}$ so that it was not necessary to vary R_e, adjustment of C alone giving a null. In the more general case R_e must be made variable with an inevitable increase in stray capacitance and inductance: these will be mainly responsible for limiting the upper frequency at which trustworthy measurements may be made.

The work described was carried out as part of the programme of the Radio Research Board. This letter is published by permission of the Director of Radio Research of the Department of Scientific and Industrial Research.

Radio Research Station,
Ditton Park,
Slough,
Bucks.

F. J. Hyde
[21 *August*, 1957]

REFERENCES

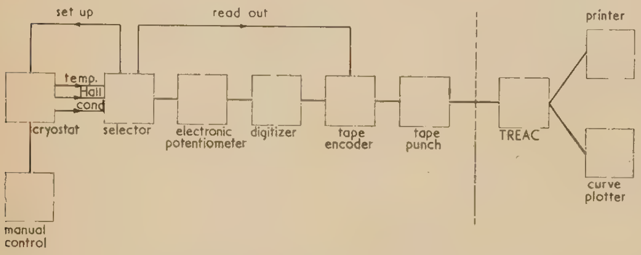
(1) Coffey, W. N. *Electronics*, **29**, p. 152 (1956).
(2) Hyde, F. J., and Smith, R. W. *Proc. Instn Elect. Engrs.* In press.

A digital recording system for measuring the electrical properties of semi-conductors

A recent letter$^{(1)}$ has described a recording system employing a self-balancing potentiometer for measuring the variation of the Hall coefficient with temperature. Systems of this type are now being widely used for measurements of various electrical properties of metals and semi-conductors. Examples include the study of the Hall effect in indium antimonide as a function of temperature and magnetic induction,$^{(2)}$ the observation of de Haas van Alphen ripples on the Hall coefficient of bismuth,$^{(3)}$ and the oscillatory magneto-resistance effect in sodium.$^{(4)}$ All these experiments require measurement in greater detail than can be readily obtained under the experimental conditions using manually operated instruments. The use of high-speed electronic potentiometers for this type of work enables observations to be made which could hardly be carried out without their use.

While the use of electronic potentiometers is vital for the examples described, the task of reading the charts is an extremely tedious one. In order to eliminate this task and to carry out speedily the computations associated with the reduction of the data, we have modified the system previously described$^{(1)}$ by attaching a digitizer to the electronic potentiometer. This enables the results to be recorded in a digital form on teleprinter tape suitable for feeding directly into an electronic computer, thus eliminating completely the task of chart reading.

The figure shows a block diagram of the system. The semiconductor is mounted in a cryostat or furnace according to the temperature range being studied. From the cryostat three outputs are fed into the selector switch. These are for measuring the temperature, Hall coefficient, and conductivity respectively. The selector switch connects these outputs in turn to the electronic potentiometer which sets to the reading. As the potentiometer balances, the digitizer follows the slide-wire setting, and when sufficient time has elapsed for the potentiometer to have balanced, a read-out signal is generated by the selector switch and is fed into the tape encoder. This is a relay store which accepts the outputs from the digitizer and arranges them in suitable form for recording on teleprinter tape. At the end of a run the tape thus produced is fed into the electronic computer TREAC which calculates the results.



Block diagram of recording system

Electronic potentiometer, Honeywell–Brown 1 s or 2½ s 1 mV F.S.; digitizer, Hilger–Watts or Giannini 0–999; tape punch, Creed perforator model 25; printer, Creed tape reader and printer; curve plotter, Dobbie McInnes digital plotting table.

The output from the computer contains the temperatures, Hall coefficients and conductivities calculated from the data, and in addition it calculates functions of them which are required for the analysis of the results, such as the reciprocal temperature, logarithms of the conductivity and Hall coefficient, and the Hall mobility. The output from the computer is punched on tape which can be used either to print the results or to operate a curve-plotting machine.

The system described has now been in use for about a year. It has enabled the number of experiments carried out to be increased by a factor of about five on what was possible before. It has been used for measurements on lead selenide, indium antimonide, indium arsenide, mercuric telluride, germanium and silicon from temperature of 2° K upwards.

Acknowledgement is made to the Controller, H.M. Stationery Office, for permission to publish this letter. Our thanks are due to Mr. P. Herman for his assistance with the construction and operation of the equipment.

Royal Radar Establishment,
Ministry of Supply,
Great Malvern,
Worcs.

R. H. A. Carter
D. J. Howarth
D. H. Putley

[18 November, 1957]

REFERENCES

(1) Putley, E. H. *J. Sci. Instrum.*, **33**, p. 164 (1956).
(2) Howarth, D. J., Jones, R. H., and Putley, E. H. *Proc. Phys. Soc. B*, **70**, p. 124 (1957).
(3) Leinhardt, T. E., and Reynolds, J. M. Private communication.
(4) Babiskin, J., and Siebenmann, P. G. *Phys. Rev.*, 1
p. 1249 (1957).

The sectioning of hard keratinous substances

It has recently been found in this laboratory that section horn, hoof and similar keratins cannot be satisfacto obtained using a normal microtome technique. A softening the keratin in Mollifex (by British Drug Hou Ltd.) and embedding in paraffin wax, sections were found be irregular in thickness and area. This variation is attribu to the slight elasticity of the cutting edge of the microto knife, which is distorted when in contact with the h keratin. The deformation of the paraffin wax embedd medium may also give rise to some irregularity.

Sections cut from horn embedded in paraffin wax w found to vary in thickness from approximately 30 μ to 70 further, this technique could only be used for small h sections. Slightly better results were obtained on us collodion as an embedding medium, but the best secti were obtained using ester wax(1) when sections of 15 μ thickness could be obtained; a variation in thickness s persisted. Such difficulties have been partially overcome using a "scraping technique."(2)

These observations suggested that a new type of microto knife was possibly required and it was found that the b

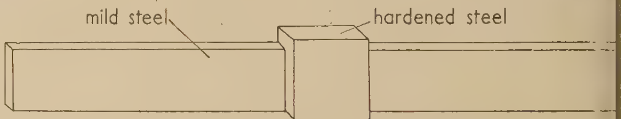


Diagram of microtome knife

results were obtained with a blade of design as in the figu A right-angled piece of hardened steel was brazed on to rectangular length of mild steel, the hardened steel th being ground and polished to give flat upper and front fa at right angles to each other. This blade was then used the normal manner with a Cambridge rocking microtom Square pieces of horn were embedded in the three med paraffin wax, collodion and ester wax, and sections cut w the new blade. With paraffin wax, sections of unifo thickness were obtained without difficulty, the thinn possible being of the order of 2 μ, and the thickest 20 In collodion, even thinner specimens were obtained. Usi ester wax as the embedding medium, sections of appro mately 1 μ in thickness could be obtained; the maximu thickness being of the order of 40 μ.

This sectioning is possible because of the high rigidity the blade. Ester wax is less easily deformed than paraf wax and hence gives better sections; the thickest specime obtainable appear to be limited by the ability of the sectio cut to clear the horizontal surface of the blade.

This technique has been found to be of value in the p paration of many other sections of hard histological specime

Department of Textile Industries,
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F. Happey
J. H. Keighley

[15 November, 1957]

REFERENCES

(1) Steedman, H. F. *Quart. J. Microsc. Soc.*, **88**, p. 1
(1947).
(2) Elliot, A., and Ambrose, E. J. *Proc. Roy. Soc. A*, 2
p. 206 (1951).

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

bration decrement measurement. A. E. Cawkell, 6–8, Victory Arcade, The Broadway, Southall, Middlesex.

is well known that measurements of the logarithmic decre- nt D of mechanical vibrations in a solid can provide useful ormation about its internal structure or serve for the tection of inhomogeneities or flaws. The type LDA equip- nt is designed for such measurements. The specimen der test, in the form of a rod, is supported at its centre on ır needle points arranged at the corners of a 1 cm square. pposite either end of the specimen are magnetic transducers ounted on slides with a micrometer adjustment. These e moved up close to the specimen for exciting and picking the vibrations. Alternatively, the specimen may be excited eddy currents, or by sticking very small iron armatures to e ends and exciting magnetically. A variable frequency cillator is used to excite the specimen, and the frequency adjusted for resonance. The instrument receives from the ck-up transducer a voltage derived from the vibrations of e specimen. When the drive oscillator is switched off, this ltage decays as the mechanical vibrations die out. As the ltage decays to a certain level, a gate is opened and the cillations are fed into a four-stage Dekatron counter. When e oscillatory voltage has decayed to a lower, pre-determined vel, the gate closes. The number of oscillations of the stem received during the time the gate is open is recorded the counter. The voltage levels at which the gate operates e so designed that the logarithmic decrement D is given by

$$D = \left(\frac{1}{N}\right) \ln 2$$

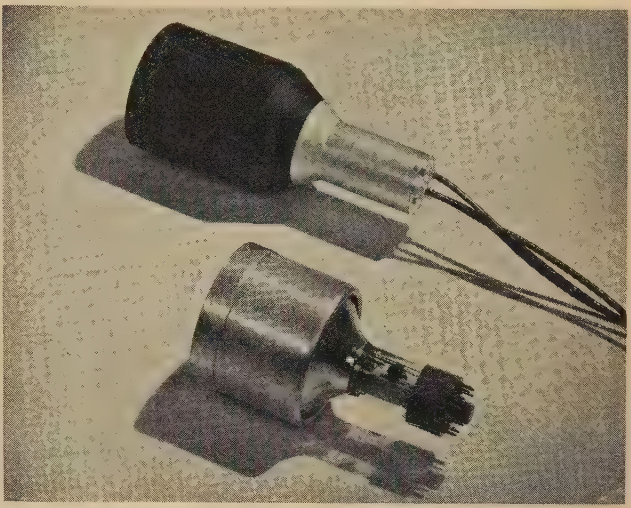
here N is the number shown on the counter. Since D is lated to the Q factor of the oscillations by the equation

$$Q = \pi/D$$

e have $Q = 4{\cdot}5N$ approximately. The instrument is pable of measuring Q's up to nearly 45 000. The makers aim an instrumental accuracy better than 2%, and state at the method can be used for quality control, indicating nall internal state differences between specimens. Special st benches are available for various specimens, shapes and zes, and successful applications include work on turbine lades, bricks, concrete pipes, steel rods and bars, nuclear aphite, ceramic and plastic specimens. It is understood at developments are in hand to make high speed automatic sting possible.

cintillation counters. Levinthal Electronic Products Inc., Stanford Industrial Park, Palo Alto, California, U.S.A.

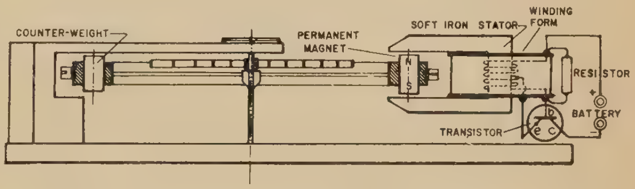
hallium-activated sodium iodide crystals for γ-ray scintil- tion counting, are now combined with a 5 in. photo- ultiplier tube and pre-amplifier in a single unit housed in a u-metal casing. The mounting of a crystal and photo- ultiplier in a single unit eliminates one interface between e two and makes the whole counter more efficient. The nits are available with any length of crystal up to 4 in., d the crystals can be provided with conical ends, drilled ells or other configurations. It is claimed that the crystals ave a very uniform distribution of thallium and have minimum optical absorption in the blue and ultra-violet to ensure efficient light transmission to the photomultiplier.



Scintillation counter unit incorporating thallium-activated sodium iodide crystal, photomultiplier and pre-amplifier

Transistor clock. C. Hunter McShan, Town House 3, Great Neck, Long Island, New York, U.S.A.

A transistor-operated electromagnet is employed as a drive for a conventional balance-wheel and hair-spring. The principle of the device is illustrated in the figure. A small permanent magnet, balanced by a counterweight, is mounted on the rim of the balance wheel. The electromagnet is placed so that the magnet passes it at the moment of its maximum velocity. The operation of the circuit is as follows. As the magnet enters the stator, the transistor remains in its normal non-conducting state and the attraction of the magnet to the soft iron stator imparts energy to the balance-wheel. As the magnet begins to leave the stator, the induced e.m.f. in the stator winding is of such polarity that it triggers the transistor to full conduction. The resulting current through the stator winding produces a magnetic field which repels the magnet out of the stator and thereby imparts additional energy to the balance-wheel. The resistor stabilizes the circuit against self-oscillation. It is stated that the relative magnitudes of the impulses given during periods of attraction and repulsion may be chosen so as to compensate the hair-



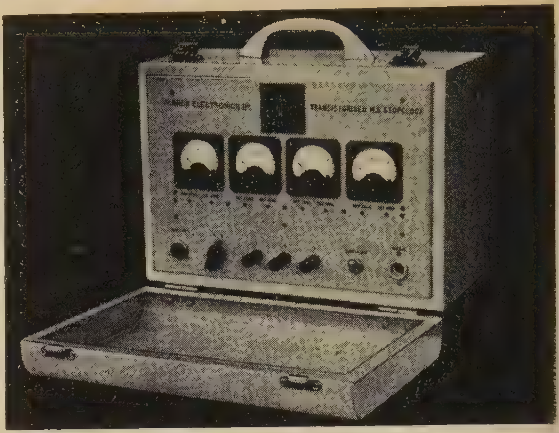
Transistor-operated balance-wheel and hair-spring assembly spring isochronal error. The driving power may be limited by magnetic saturation. It is possible to use the stator to drive both the balance-wheel and a gear-stepping armature, thus enabling the balance-wheel to operate under free-swinging conditions. A typical model utilizes a 1 g balance-wheel of diameter 1·75 cm. With a power input of 8 μW, the excursion is $\pm 270^\circ$ and the duration of the impulse is 10^{-3} of the beat period.

Combination magazine and processor. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A.

The 5–036 Datarite magazine is intended as a photographic attachment to a standard oscillograph. It provides *developed and dried* photographic records on a silver halide emulsion paper at speeds up to 25 in/s. The mains-operated magazine has a nominal capacity of 400 ft of 12 in. paper. It measures $15\frac{1}{2} \times 13 \times 11\frac{1}{4}$ in. and weighs 55 lb when fully loaded with developer and a 400 ft roll of paper.

Millisecond stopclock. Venner Electronics Ltd., Kingston By-Pass, New Malden, Surrey.

The type TSA4 stopclock, illustrated in the figure, is designed for all types of time measurement and covers the range from 0·1 ms to 27·8 h. The instrument is constructed from nine transistorized packaged stages, the basic time standard being a transistorized crystal oscillator operating at a frequency of 10 kc/s. Pulses from the oscillator are passed *via* a gate to four transistorized decade counters and thence to a mechanical counter. The division ratio provided by the four decade such that the counter receives 1 pulse/s. The elapsed time be read in seconds from the counter, the four decimal pl being taken from the meters calibrated 0–9 which are c nected to the decades. The gating is arranged so that closed or open times of contacts can be measured, or time between one pair of contacts opening or closing another pair opening or closing. Pulse operation is a catered for, as a positive pulse can be used to start or s the instrument. The power consumption of the instrum which uses 46 transistors, is 1 W at 12 V.



Transistorized electronic stopclock

New books

"AnalaR" standards for laboratory chemicals. 5th Revised Edition. (Poole: The British Drug Houses Ltd.; Chadwell Heath: Hopkin and Williams Ltd.) Pp. xvi + 397. Price 21*s*.

Physicists and chemists in modern laboratories, whose work requires a knowledge of the standard of purity of their compounds, have become so accustomed to having available the wide range of "AnalaR" materials that they must sometimes forget the valuable service which British Drug Houses Ltd., and Hopkin and Williams Ltd., perform in this respect. The preface to the first edition tells an interesting story of the development of the present organization. As Professor Jocelyn Thorpe pointed out in the foreword to the first edition of the book, this happy state of affairs did not always hold, and it is salutory to reflect on the difficulties which might arise if "AnalaR" chemicals, with their guaranteed maximum limits of impurities became no longer available. Fortunately this seems unlikely; the fifth edition gives the present list of over 300 "AnalaR" products, covering an impressive range of inorganic and organic compounds, and precipitation and complexing reagents. Twelve products included in the fourth edition have been discontinued and fourteen new products appear for the first time in this edition. Under each name is given the maximum impurity limits and a precise statement of the methods by which the purity was established. These form a particularly useful guide to appropriate analytical techniques. A series of seven Appendices describe particular methods which have found increas application.

Although the major purpose of the book is to catalo the "AnalaR" standards at present being produced, it conta such a wealth of analytical detail that for this reason als forms a valuable reference text.

C. C. ADDISO

An introduction to transistor circuits. By E. H. COO YARBOROUGH. (Edinburgh: Oliver and Boyd L 1957.) Pp. xii + 154. Price 15*s*.

In spite of its small size this book makes a useful addit to the literature on transistors. It is based mainly on author's work at Harwell. The first chapter on the princip of transistor action is an excellent summary; it will be p ticularly appreciated by those who already have so knowledge of the physics of semiconductors. There foll two chapters on small signal amplifiers. The remaind about half of the total, deals with non-linear circuits various types for pulse generation, switching, counti scaling and computing. Among the more obvious omissio are power amplifiers, r.f. amplifiers and sinusoidal oscillato It is a pity that Mr. Cooke-Yarborough has limited hims so severely, since he gives a clear and authoritative accou within his limited scope.

M. R. GAVIN

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

ectifiers and thermistors. R. H. Cole (Overseas) Ltd., axton Street, London, S.W.1. Two illustrated booklets ribes selenium rectifiers for radio and television, and mistors manufactured by Siemens and Halske. The fiers are for ratings met with in normal radio and tele- on engineering and, although they are very small, have a output current capacity.

ume cupboard fans. Griffin and George, Ltd., Ealing d, Alperton, Wembley, Middlesex. Publication V3461 ribes Woods polythene protected Aerofoil fume cupboard which, it is claimed, extract fumes without the motor or ng being impaired.

ingle crystal goniometer. Unicam Instruments Ltd., ury Works, Cambridge. Catalogue No. S35 describes a le crystal Weissenberg goniometer. It can be used for ormal techniques requiring film movement synchronously crystal oscillation.

-ray diffraction camera. Unicam Instruments Ltd., ury Works, Cambridge. Leaflet S70 gives details of a m high temperature powder camera for X-ray analysis to 1000° C. The camera used is a standard 19 cm ye–Scherrer type.

hermal relays. Mercia Enterprises Ltd., Godiva House, sley Old Road, Coventry. Publication EC/587 describes basic G-V types of thermal relays and also includes a nber of supplementary bulletins on specialized devices and ain applications.

utomatic voltage regulators and stabilizers. Claude Lyons ., Valley Works, 4–10 Ware Road, Hoddesdon, Hertford- e. Catalogue S574 describes automatic voltage regulators stabilizers, an earth loop tester and activities in the a.c. omatic voltage stabilization field.

Magnetic automatic computer. Texas Instrument Incor- ated, Industrial Instrumentation Division, 3609 Buffalo edway, Houston, Texas, U.S.A. Bulletin No. S-318 cribes the SeisMac electronic processing computer and related equipment for central office processing. The letin also gives details of other components: the MagneDisc -type magnetic recorder, 7000B amplifier and the T-Z ne-depth) camera.

Non-destructive testing instruments and unit pulse equip- nt. A. E. Cawkell Ltd., Southall, Middlesex. A 32-page strated booklet describes two instruments for measuring n-destructively certain properties of engineering materials. del UCT is used to measure the time of propogation of pulse of longitudinal vibrations of ultrasonic frequency ough the specimen. Model SCT is used to measure the onant frequency of the specimen by mechanically con- ting it to a vibrator, the frequency being varied until onance is reached. The third edition of a 16-page strated booklet describes pulse and trigger generators, ay units, a time calibrator, an amplifier and a 10-channel lti-pulse generator.

Gas-liquid chromatographic apparatus. Griffin and George ., Ealing Road, Alperton, Wembley, Middlesex. Cata- ue P2034/5707 describes the VPC gas-liquid chromato- phic apparatus. This enables the separation of com- ents in mixtures up to boiling points of about 350° C, recorder tracing a permanent record of the analysis.

Ion exchange resins. Bio-Rad Laboratories, 800 Delaware Street, Berkeley, California, U.S.A. Price list "M" contains a list of specific types of resins which can be produced and a bibliography of books and reviews pertaining to the subject of ion exchange.

Quartz spectrographs. Jobin and Yvon, 26 Rue Berthollet, Arcueil (Seine), France. A 15-page illustrated brochure describes three spectrographs and ancillary equipment. These are: type Z3 for the range 2050–9000 Å; type NZ for the range 2280–4500 Å, and type Z for the range 2100–7000 Å.

Slicing and dicing machine. The DoALL Company, Des Plaines, Illinois, U.S.A. An illustrated leaflet No. 56–70 1–57 describes a precision production slicing and dicing machine for hard, brittle, friable materials. Details of accessories for this machine are also given.

Stabilizers. Claude Lyons Ltd., Valley Works, Ware Road, Hoddesdon, Hertfordshire. A leaflet describes the addition to a range of cabinet mounted a.c. stabilizers of a range of similar stabilizers designed for incorporation in standard Post Office 19 in. racks.

High-vacuum equipment. Consolidated Electrodynamics Corporation, 300 North Sierra Madra Villa, Pasadena, California, U.S.A. An illustrated catalogue lists high-vacuum equipment for laboratory and industrial applications including high-vacuum pumps. Descriptions are given of valves, baffles and traps; high-vacuum gauges; leak detectors; high-vacuum metallizing equipment; high vacuum furnaces; processing equipment for the electronic industry.

The non-destructive testing of engineering materials. A. E. Cawkell Ltd., Southall, Middlesex. The second edition of a 24-page booklet gives details of the non-destructive testing of engineering materials with particular reference to their internal structure and properties.

Miniature bearings. Miniature Bearings Ltd., 39 Parliament Street, Westminster, London, S.W.1. The latest RMB catalogue of miniature ball and roller bearings, published in November 1957, renders obsolete all previous editions. The principal changes are (1) the discontinuance of series E, O and OT; (2) the addition of series NUS roller bearings, corresponding to series NU without inner races.

Electrothermal heating mantle. Electrothermal Engineering Ltd., 270 Neville Road, London, E.7. Publication No. 313 gives details of the MY series of heating mantles. This range of heating mantles is aluminium-housed and is fitted with reliable elastic and all-flexible heating. Models are also available with a bracket to accept support rods.

Storage equipment for drawings. Randalrak Ltd., 106 Victoria Street, London, S.W.1. A leaflet describes equipment for storing, filing, and transporting drawings.

Rigid mouldings from natural rubber. The Natural Rubber Development Board, Market Place Buildings, Mark Lane, London, E.C.3. Broadsheet No. 6, entitled: "Hard moulding compositions from modified natural rubber" gives full details of compounding and physical performance of a range of compositions made from cyclized rubber and Heveaplus MG. The compositions are divided into two classes. The first is suitable for multi-daylight presses and hand operated multi-cavity moulds and the second for plastic moulding, using tools with automatic injection.

Notes and comments

The British Group for computation and automatic control of the British Conference on automation and computation

The rapid growth of automation, in which is comprised computation, process control and data processing generally, led to a decision by some twenty bodies of the learned society type having interests in these fields, or in their social and economic implications, to set up a central organization to provide more effective liaison between the interested bodies, to be known as the British Conference on automation and computation. This has been organized in three Groups, (*A*) The British Group for the engineering applications of automation, (*B*) The British Group for computation and automatic control, and (*C*) The British Group for the sociological and economic aspects of automation techniques.

At a meeting held on 20 December, 1957, Group (B) was formally constituted, comprising as its members twenty-three societies and institutions including the Institute of Physics.

The objects of the Group are: "(*a*) to foster the development and applications of automatic controls, computing and data processing equipment and programming techniques, (*b*) to afford a common meeting ground for the adhering organizations whereby such of their activities as fall within the purview of the Group can, if so desired, be co-ordinated and extended, (*c*) to maintain, as may be desirable, liaison with other Groups of the British Conference on automation and computation by direct contact and by representation on the General Committee of the British Conference, (*d*) to encourage and, if desired, to co-ordinate the presentation at International Conferences of British papers whose subjects fall within the purview of the Group, and (*e*) through the General Committee of the British Conference on automation and computation, to maintain, as may be desirable, liaison with corresponding National Committees of other countries which support such International Conferences."

The executive committee of the Group consists of the Honorary Officers together with the representatives of six of the constituent bodies, including the Institute of Physics.

The Group constitution provides for the election of additional member societies: those interested should communicate with the Honorary Secretary, B.C.A.C., Group (B), c/o The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Register of British manufacturers

The 1958 edition of the F.B.I. register of British manufacturers provides a comprehensive guide to a substantial cross-section of British industry, listing the products and services of over 7500 firms who are members of the Federation of British Industries, under more than 5400 alphabetical headings. The headings used are: products and services, addresses, trade associations, brands and trade names, marks. In addition there are language glossaries in Fre German and Spanish.

The register is published by Kelly's Directories Ltd., Iliffe and Sons Ltd., Dorset House, Stamford Street, Lon S.E.1. The price is 42*s*.

Comments on the A.S.T.M. Powder Data File—3

A third booklet has been prepared by Dr. J. W. Hug Miss I. E. Lewis and Prof. A. J. C. Wilson, bearing the a title, which contains further additions to the lists previo published and described in The Institute's Journals.* Co of the present booklet are being distributed in the same as were the others. Those who do not receive copies of booklet in this way may obtain them (free of charge request from The Institute of Physics or from the autho the Viriamu Jones Laboratory, University College, Ca S. Wales.

It is hoped that similar lists of comments will be publi at approximately annual intervals. Users of the Data are urged to send to the authors any material that they should be included in future issues.

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* HUGHES, J. W., LEWIS, ISABEL E., and WILSON, A. J. *J. Sci. Instrum.*, **34**, p. 211 (1957). *Brit. J. Appl. Phys.*, **8**, p. (1957).

British Journal of Applied Physics

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New books

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ORIGINAL CONTRIBUTIONS

An improved Czochralski crystal-pulling furnace

By K. H. J. C. Marshall and R. Wickham, Services Electronics Research Laboratory, Baldock, Herts.

[*Paper first received* 18 *September, and in final form* 30 *October*, 1957]

A furnace suitable for pulling single crystals of germanium and silicon has been made. This apparatus differs from previous designs in that it combines rapidity of set-up with ease of operation and almost perfect vision during the crystal-growing cycle. The heating element is of resistance heated graphite and provision is made for growing either in vacuum or in an inert gas atmosphere.

r semiconductor work preparation of material in the form single crystals is necessary. A well-known method for owing single crystals from a melt whereby a seed crystal is aced in contact with the melt and then slowly withdrawn rough a vertical negative temperature gradient has been scribed by Czochralski.(1) This method has been applied th success to germanium(2,3) and silicon,(4) the elements w in general use for semiconductor devices, but the pulling these single crystals is usually done in an inert atmosphere th the attendant difficulty of obtaining an inert gas free om harmful impurities. The use of high vacuum growing nditions provides a useful alternative which eliminates this fficulty. A successful vacuum furnace has been described ewhere,(5) but its use appears to have been limited to lling germanium crystals on a laboratory scale.

Experience has shown that the essential requirements for a ystal pulling furnace can be considered under the following adings: choice of materials; method of heating and control; echanical design; vacuum pumping arrangement; inert gas rangement.

CHOICE OF MATERIALS

The working chamber must be made of a material which n be easily fabricated for vacuum work, can be easily achined, has good conductivity, is readily available and is ch that no serious damage to the charge would result ould any small particles of it inadvertently get into the melt.

The material chosen, which conforms very well with these quirements was M.G.5, a 5% magnesium aluminium alloy anufactured by James Booth and Co. Ltd. of Birmingham. e chamber is fabricated from 1 in. plate by the argon-arc elding process, and on initial test showed a leakage rate s than 10^{-6} l.mb/s. Suitable water cooling of the chamber duces the working temperature of the inside faces to the gion of 100° C.

The internal fittings of the chamber, which must be restricted materials known to be least contaminating at high temratures, are molybdenum and the purest graphite obtainable temperatures near 1450° C, with quartz and stainless steel to 1000° C.

HEATING METHOD AND CONTROL

The crucible temperature must be controlled to within ±1° to the region of 1450° C, and there are two methods of ating that can be employed; induction heating and resistance ating.

Induction heating and its associate equipment is expensive d difficult to control in vacuum melting processes owing to rona discharge or "arcing over" when the work coil is inside the chamber. On the other hand, resistance heating is relatively cheap and rather more easily controlled. Although spiral graphite heaters have been used by other workers to produce the required vertical temperature gradient a more easily manufactured heater was adopted using the basic design indicated by Blakelock and Machin(6) and is shown in Fig. 1. It is machined from stock graphite tube grade EY9A (by the Morgan Crucible Co. Ltd.) or Harwell Grade A block. The lugs are made separately and fixed by molybdenum screws.

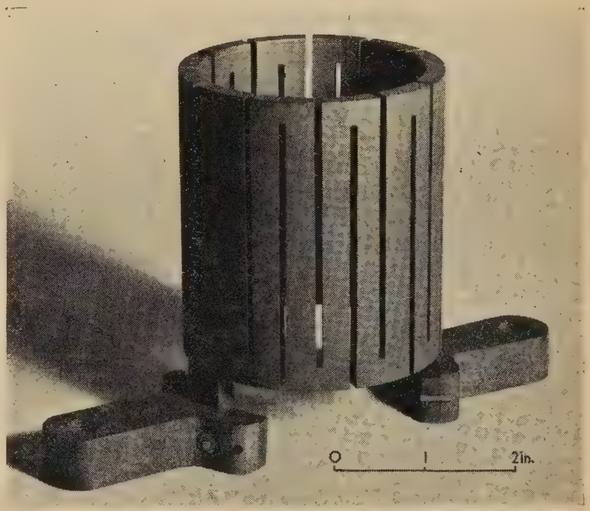

Fig. 1. Detail of heater

The design of the heater is such that the two halves are in parallel with a combined resistance $\frac{1}{6}\,\Omega$. (A diagram of the heater circuit is shown in Fig. 2.) The supply to the heater, taken from the mains, is varied by two Variac transformers. The larger Variac changes the bulk of the supply, *via* a 230/50 V step-down transformer, capable of delivering 300 A at 50 V. The smaller Variac, operated by a proportional d.c. motor, supplies a 230/5 V step-down transformer, the secondary of which is in series with the secondary of the 230/50 V transformer to supply the heater. The voltage of the heater is rectified and compared with a neon-stabilized reference voltage—any differences are amplified and fed to the proportional motor controlling the small Variac, thereby correcting the supply. Any small changes required in power can be made by varying the reference voltage.

A platinum/platinum-rhodium thermocouple is placed in an alumina protective tube as close as possible to the top of the heater. The temperature measured at this point is used purely as a reference for the operation and not for a control. From the temperature recorder the operator can observe the rate of change he is applying and, by knowing the thermal time constant of the furnace, at present 2 min, he can determine when the full effect of the change has been made.

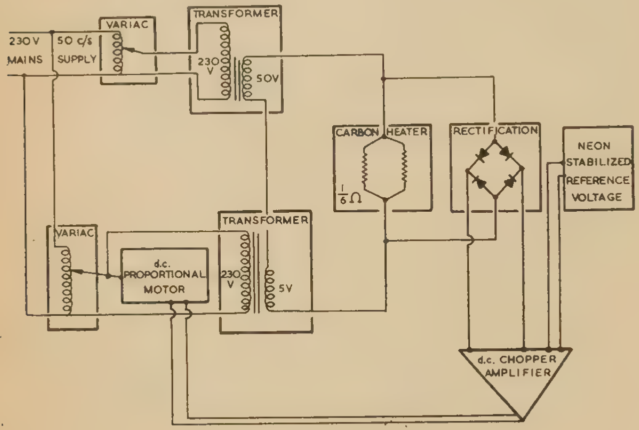
230 V
MAINS
50 c/s
SUPPLY
VARIAC
TRANSFORMER
230 V
50V
CARBON HEATER
1/6 Ω
RECTIFICATION
NEON
STABILIZED
REFERENCE
VOLTAGE
VARIAC
d.c.
PROPORTIONAL
MOTOR
TRANSFORMER
230 V
5V
d.c. CHOPPER
AMPLIFIER

Fig. 2. Controlled voltage heater supply
(Maximum 50 V 300 A) 15 kW.

MECHANICAL DESIGN

The general arrangement of the furnace is shown in Figs. 3 and 4 and a photograph of the complete apparatus in Fig. 5.

The chamber is made as a complete box in which grooves for water cooling are cut externally to within $\frac{3}{16}$ in. of the internal face. These grooves are covered with plates on w manifolds are fitted for water inlet and outlet. Becaus the possible electrolytic action in the system, all fixing s are of cadium-plated steel. The studs have coarse thr in the chamber wall and fine threads for the nuts. Each face has its own cooling system which is arranged so tha vacuum O-rings between the chamber and Wilson bodies are water washed. There are further water supp to the electrodes, framed quartz viewing windows, pumping elbow. To avoid condensation troubles within chamber when open to atmosphere, the water is pum from a static tank which is at room temperature.

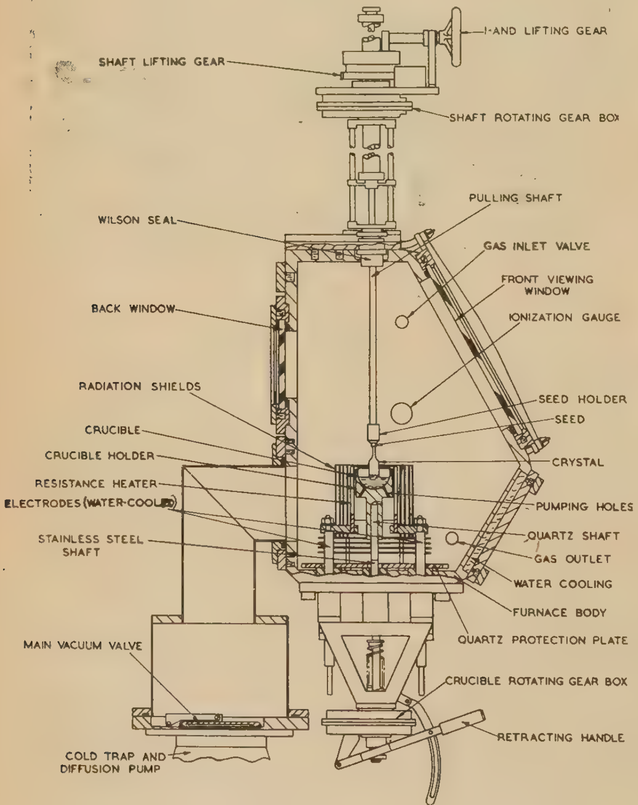
HAND LIFTING GEAR
SHAFT LIFTING GEAR
SHAFT ROTATING GEAR BOX
PULLING SHAFT
WILSON SEAL
GAS INLET VALVE
FRONT VIEWING WINDOW
BACK WINDOW
IONIZATION GAUGE
RADIATION SHIELDS
SEED HOLDER
SEED
CRUCIBLE
CRUCIBLE HOLDER
CRYSTAL
RESISTANCE HEATER
ELECTRODES (WATER-COOLED)
PUMPING HOLES
STAINLESS STEEL SHAFT
QUARTZ SHAFT
GAS OUTLET
WATER COOLING
FURNACE BODY
QUARTZ PROTECTION PLATE
MAIN VACUUM VALVE
CRUCIBLE ROTATING GEAR BOX
RETRACTING HANDLE
COLD TRAP AND DIFFUSION PUMP

Fig. 3. Part sectional side view of furnace

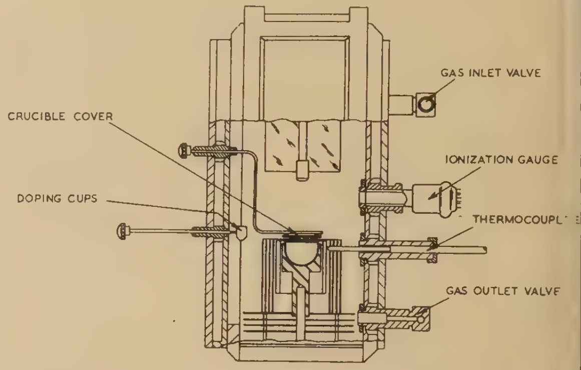
GAS INLET VALVE
CRUCIBLE COVER
IONIZATION GAUGE
DOPING CUPS
THERMOCOUPL
GAS OUTLET VALVE

Fig. 4. Part sectional front view of furnace

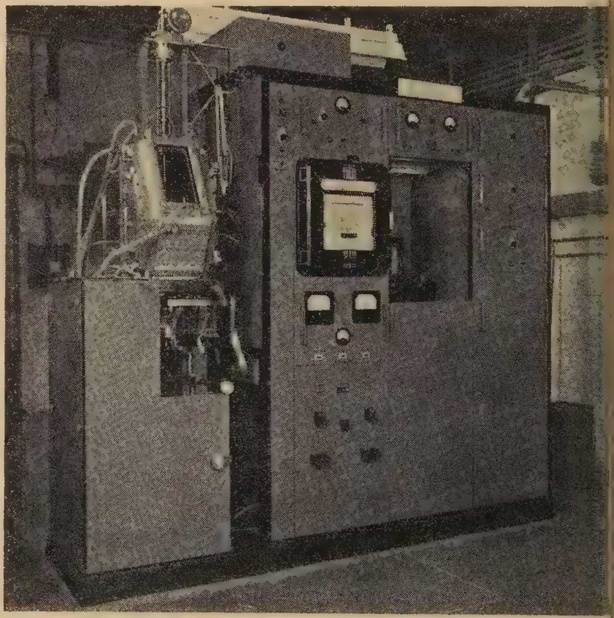

Fig. 5. General view of furnace

A detachable transparent quartz window, 12 × 6 × $\frac{3}{8}$ thick, in a water cooled frame is vacuum sealed to the slop front by means of a large O-ring held by wing nuts. T window ensures almost perfect vision during the cry growing cycle. A similar smaller viewing window, 6 × 6 $\frac{3}{8}$ in. thick, is fitted for observation from the back.

Speedy access to the inside of the furnace for quick remo and replacement of heater, radiation shields, crucible, etc. made through a large water-cooled door on the side of amber (Fig. 4), vacuum sealed by a large O-ring held by ng nuts.

With this box construction the alinement of the top and ttom shaft is consequently permanent and contributes aterially to the desired geometric symmetry. This contrasts the more usual design where the top of the furnace must removed each time the furnace is re-charged.

The chamber is vacuum-pumped from the back through a in. water-cooled stainless steel elbow, thus leaving the ottom of the chamber free to accommodate the water-ooled silver heater electrodes and the crucible rotating and wering mechanism. In this way baffling of the pumping ystem by internal fittings is made negligible.

Raising and lowering of the crucible in the heater gives dded flexibility in determining the form of the liquid-solid terface and assists during the initial melting down. The esign of the heater is such that it is hottest in the middle ith a vertical temperature gradient to each end. During ulling the crucible is positioned in the upper half of the eater. This position is sometimes unsuitable for the melting own process with some forms of undensified material. With ese materials the bottom of the charge melts before the top, aving a sintered crust out of contact with the melted portion f the charge. Any deliberate overheating to try to over-ome this is both undesirable and dangerous. Only a few egrees above the melting point of silicon the reaction between licon oxide and silicon is accelerated and movement of the quid may be so violent as to actually eject droplets of silicon rom the crucible. Lowering of the crucible in the heater llows radiation on to this crust, and this, combined with a etractable radiation shield over the top, assists in a quick nitial melting.

The crucible is held in a graphite holder, care being taken o ensure a good fit to reduce the possibility of cold spots. This is done by using the same profile tool for making the rucible mould and graphite holder. Small pumping holes re drilled in the base to avoid the danger of trapped gas, esulting from the reaction between quartz and carbon at levated temperatures, forcing the crucible out of the holder.

To avoid undue heat conduction down the crucible support o the rubber in the Wilson seal below, a centreless-ground uartz rod is fitted between the graphite holder and the tainless steel shaft. As an additional precaution, a trans-ucent quartz plate is fitted in the bottom of the chamber to rotect the aluminium alloy from molten silicon in the event of a crucible failure.

Two retractable quartz doping cups are fitted to the inside of the door for convenience of loading and are manipulated xternally through small Wilson seals (Fig. 4).

The independent rotation of the crucible and molybdenum eed chuck and the vertical movement of the stainless steel ulling rod are achieved by variable speed servo-motors Velodynes) suitably geared down. To reduce vibration at he melt to a minimum this high-speed rotating gear is mounted on the independently supported control and power nit chassis which is immediately adjacent to the chamber. Rotation of the slow speed worm and worm-wheel assemblies on the chamber is imparted by shafts with flexible couplings. The movement of the pulling rod is achieved by a pair of spring-loaded half nuts working on a square-threaded hollow shaft. To permit raising and lowering the rod by the hand-wheel these half nuts can be quickly disengaged by turning a cam plate at the top.

Provision is made for crucible and seed rotation up to 50 rev/min in both directions, with a maximum movement of 25 cm/h in both directions on the pulling rod.

VACUUM PUMPING ARRANGEMENT

To further assist quick melting of the charge, a high speed vacuum pumping system is used to restrict the pressure of gases liberated during heating to a minimum.

The vacuum system consists of a type 603 three-stage silicone oil diffusion pump (by Edwards High Vacuum Ltd.) capable of pumping at 600 l./s connected in the usual way to a mechanical backing pump type 559 (by Metropolitan-Vickers Ltd.). A mercury diffusion pump cannot be used because of the risk of mercury-aluminium amalgamation should any mercury inadvertently enter the chamber.

The diffusion pump is cold trapped by a liquid nitrogen trap of high effective aperture. This prevents any back streaming of the oil vapour into the work chamber, and so eliminates the danger of cracked, hygroscopic oil deposits, which would adversely affect pumping rates, and would be extremely difficult to remove.

Immediately above the nitrogen trap is the main vacuum valve(7) specially designed to minimize the throttling effect on the pump. Pumping is done from the back of the chamber through a 6 in. water-cooled stainless steel elbow, and the effective pumping speed of this system is estimated to be of the order of 150 l./s. A further two Gaco rubber-seated valves are included to allow initial roughing-out of the chamber to the required pressure before bringing the diffusion pump into service. An ionization gauge is sited immediately adjacent to the melt to allow pressures to be measured in the chamber during operation.

INERT GAS ARRANGEMENT

Gas inlet and outlet valves are fitted to the top and bottom of the chamber at the side. Owing to the fact that hot gas will be passing through them, the valves are made with special indium seats using the design principles outlined by Godwin.(8)

OPERATION

Vacuum pulling. Before starting growing operations the chamber is thoroughly cleaned. The crucible to be used is prepared by a 15 min etch in an HF/HNO_3 solution followed by a thorough washing in de-ionized water. The seed to be used is cut ¼ in. square from a previously grown crystal, which prior to cutting is orientated by use of a back-reflexion X-ray camera to within 1° of the axis on which the crystal is to be grown. The sharp corners of the seed stock are ground away at the growing end and the seed is given a polish etch in equal parts of hydrofluoric, nitric, and acetic acids. The operator works with Nylon-gloved hands to maintain a high standard of cleanliness whilst loading the chamber. The charge is loaded into the crucible from the manufacturer's container and weighed; no cleaning of the charge takes place, as this can be more harmful than good.

With charge and seed loaded, the chamber is closed and rapidly evacuated to approximately 5×10^{-6} mb. The heater is switched on and power gradually increased to that required for melting. By experience it is known that a 70 g charge requires approximately 5·5 kW to melt over a period of some 20 min. As soon as the charge is fully molten the seed is lowered into close proximity with the liquid. By watching the temperature recorder it can be seen that removal of the top radiation shield and closeness of the seed causes the temperature to fall rapidly. After some 4 min, when the temperature has stabilized, the seed may be introduced into the melt and the temperature will again fall. The appearance of the liquid meniscus around the seed informs the operator as to whether the seed is sufficiently wetted to start growing operations. The interpretation of the seed-meniscus picture can only be gained by experience, and the operator is able to make slight adjustments to the power until he is satisfied that conditions are right. In order to grow, the lift rate is started at 1 cm/h and the temperature set to fall slowly, the rate of fall being noted from the temperature recorder. As soon as small facets appear, indicating that the crystal is growing outwards, the lift rate is gradually increased, still maintaining a falling temperature, to 11 cm/h. When the operator is satisfied that the crystal is approaching the desired diameter he increases the temperature gradually until the ingot is growing at constant diameter. As the level of liquid falls the temperature is also made to fall slightly to maintain constant diameter. The total growing time for a 70 g crystal of 2 cm diameter at 11 cm/h is approximately 45 min. A record of the temperature variation during a typical run is shown in Fig. 6.

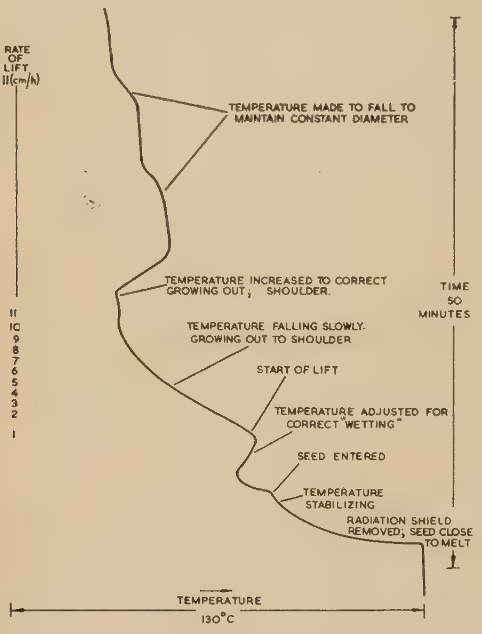

Fig. 6. Temperature variation during crystal growth
Seed rotation 10 rev/min; crucible rotation 2 rev/min.

With experience, using a hemispherical type crucible as manufactured by the Thermal Syndicate Ltd., an operator can successfully remove all silicon from the crucible and the crucible can be used repeatedly. With this apparatus a crucible has been used eight times before becoming so thin from etching and absorption into the melt that it has had to be discarded. During the growing period the gases given off by the various reactions taking place increase the pressure to approximately 1×10^{-4} mb, but as soon as the power is switched off the cooling graphite will act as a getter and reduce the pressure to better than 2×10^{-6} mb. Doping to predicted resistivities in vacuum is achieved by use of a phosphorus/silicon[9,10] alloy to dope *n*-type and a boron/silicon alloy to dope *p*-type. Because of its volatility the phosphorus must be added from a doping cup after melting and just prior to growing. The boron alloy, however, can be added to the charge before loading.

Gas pulling. To date no attempt has been made to pull crystals in gas, but it has been established that the changed thermal conditions associated with gas pulling can accommodated by the furnace.

It has been noticed that the effect of crusting during melt down is not nearly so troublesome in gas pulling, probab due to the convectional heating throughout the charge of t hot gas. A further effect noticed is that in vacuum pulli any scum on the liquid is gradually reduced, but in g pulling the scum is retained and, if the gas is not pure, m even be increased.

RESULTS

To date, some sixty crystals have been vacuum-grown this furnace. Of these sixty, five were twinned or bi-crystallin one, from a very inferior material, was poly-crystalline, a fifty-four were single crystals. On the sixteen occasions wh the charge consisted of well-known Dupont material t grown crystal was single. The twinned and poly-crystalli ingots were grown from very inferior non-densified mater and cannot be considered as a measure of the performance the equipment.

Phosphorus doping to predicted resistivities has produc a range of *n*-type material from 0·05 Ω to 60 Ω cm, while range of *p*-type material from 0·026 Ω cm to 40 Ω cm h been achieved by doping with boron from 30 to 0·003 pa per million by weight. Evaluation pulls of manufacture samples have produced *p*-type crystals up to several hundr ohm centimetres.

Life-time measurements by the light-spot technique certain of the crystals have covered a range of 12 μs for 1 Ω c *p*-type to 140 μs for 120 Ω cm *p*-type. Dislocation densi measurements made with the G.E. etch[11] have shown average of 3×10^3 per cm^2 at the outside of the crystal wi 5×10^2 per cm^2 at the centre of the crystal.

CONCLUSIONS

Work has now been in progress with this type of appara for approximately six months, producing crystals for devi development and evaluating various manufacturers sampl During this period the furnace has behaved satisfactorily every respect, and has proved quite easy to operate.

With the aid of a coloured water cell there has been discomfort to the operator from either radiated heat intense light, and excellent vision is obtainable at all tim through the quartz viewing windows. The view presented the operator from the front window is shown in Fig. which also shows a typical single crystal of silicon. On the thermal conditions of the furnace have been learned it reasonable to suppose that, with a known charge weigh the thermocouple and temperature recorder can be dispens with and automatic programming introduced after the "jo on" and "shouldering" have been completed.

The alloy M.G.5 has proved itself to be a useful vacuu chamber material and is recommended for use elsewhe The continued efficient working of the vacuum syste described has been largely due to the permanent box co struction of the chamber, where only one seal (on the doo has to be broken and remade between pulling operation The main vacuum valve which must be fitted for the inert arrangement has shown itself to be invaluable in vacuu work. Closure of this valve isolates completely the wo chamber from the pumping system, so that re-charging, et can be done without shutting down the pumping system.

Although the procedure described here is for silicon, alternative sub-assembly of crucible, heater and radiati ields could easily be fitted to enable work to be done with ermanium. It must be stated, however, that growing ystals in vacuum has one drawback, namely, the choice of oping agents is restricted to those with favourable vapour ressures.

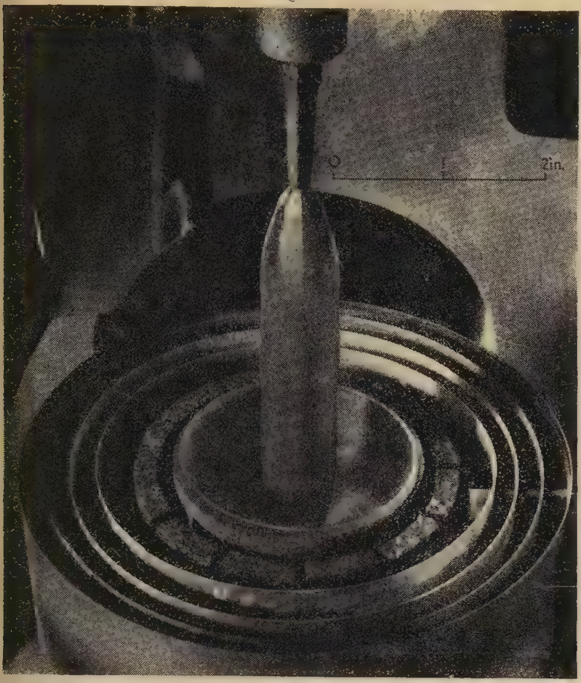

Fig. 7. Heater assembly with finished crystal

ACKNOWLEDGEMENTS

The authors wish to acknowledge the discussion with Mr. N. J. Golden of Sylvania-Thorn Colour Television Laboratories, Enfield, Middlesex, from which this project was started. Also their indebtedness to Mr. F. E. Birbeck for his assistance in the mechanical design and to Mr. J. Raines for much of the detailed work in operation of the apparatus and evaluation of results.

Acknowledgement is also made to the Admiralty for permission to publish this paper.

REFERENCES

(1) Czochralski, J. *Z. Phys. Chem.*, **92**, p. 219 (1918).
(2) Teal, G. K., and Little, J. B. *Phys. Rev.*, **78**, p. 647 (1950).
(3) Roth, L., and Taylor, W. E. *Proc. Inst. Radio Engrs*, **40**, p. 1338 (1952).
(4) Teal, G. K. *Phys. Rev.*, **87**, p. 221 (1952), title only.
(5) Lehovec, K., Soled, J., Koch, R., Macdonald, A., and Stearns, C. *Rev. Sci. Instrum.*, **24**, p. 652 (1953).
(6) Blakelock, H. D., and Machin, C. F. *Engineer*, **196**, p. 83 (1953).
(7) Services Electronics Research Laboratory drawing No. C.2061, Valve No. 14 modified.
(8) Godwin, D. W. *Services Electronics Research Laboratory Tech. Memo.* No. 134 (1954).
(9) Bradshaw, S. E., and Mlavsky, A. I. *J. Electronics*, **2**, p. 134 (1956).
(10) Bradshaw, S. E., and Mlavsky, A. I. *Report Meeting on Semiconductors* (London: The Physical Society, April 1956).
(11) Dash, W. C. *J. Appl. Phys.*, **27**, p. 1193 (1956).

An a.c. velodyne integrator

By J. B. Sharp* and R. W. Williams, Ph.D., A.Inst.P., The English Electric Company Ltd., Stevenage, Herts.

[*Paper received* 19 *September*, 1957]

An electromechanical integrator is described which is an a.c. version, operating with 50 c/s signals, of the well-known velodyne principle. The difficulties peculiar to the a.c. velodyne are summarized and the features of the design, by which these are overcome, are indicated. The accuracy of integration is discussed, with special reference to the errors caused by Coulomb friction, to transient response and to temperature effects. Integrators of the type described have given satisfactory service for some years in a large special-purpose analogue computer.

INTRODUCTION

he velodyne principle has been established for several years a means of evaluating time integrals in electromechanical nalogue computation. As originally described,(1) the lodyne was a d.c. system, but the principle is equally appliable to the a.c. case. The essentials of an a.c. velodyne are own in Fig. 1; M is a two phase induction motor the conolling phase of which is fed from a servo amplifier of high in. The motor is mechanically coupled to a two phase duction generator, G, whose output is proportional to the eed of rotation. The input terminal of the amplifier is ken to the junction of the summing arms R_1, R_2, to which e applied respectively the input signal to the integrator, e, d the output of G. Neglecting transient and non-linear effects, it follows that the angular rotation of the motor shaft is proportional to $\int e\,dt$. There are several problems peculiar to the a.c. velodyne and the present paper is devoted to an examination of these, and to the description of a practical

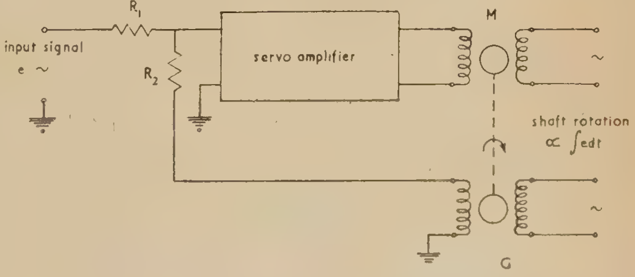

Fig. 1. Schematic diagram of an a.c. velodyne

design, operating with 50 c/s supplies and signals. Integrators based on this design have given satisfactory service for some years in a large special-purpose computer.

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* Now at C.E.R.N., Geneva, Switzerland.

DESIGN PROBLEMS

The principal difficulties encountered in the design of an a.c. velodyne may be summarized as follows:

(i) instability caused by backlash in the mechanical coupling between motor and generator. The components selected for use in the integrator to be described were the standard magslip 2 in. motor (British Services No. 10743) and the 2 in. generator (British Services No. 10877) which are available only as separate elements.

(ii) instability arising from phase shifts in the servo amplifier in the region of the carrier frequency. The importance of this source of instability ("envelope delay") has been emphasized by Langham.(2) It has been customary in past designs deliberately to provide an overall phase shift of 90° at the carrier frequency so as to obtain maximum torque from the servo motor, the energizing voltage applied to the motor reference winding being co-phased with the computing signals.

(iii) saturation of the servo amplifier by the harmonic content of the error signal applied to it.

(iv) when its rotor is stationary, the generator furnishes a small but significant output signal whose amplitude varies cyclically with the rotor position.

(v) the time phase of the output of the generator lags that of its excitation.

The first difficulty has been overcome by mounting the motor and generator in line so that their rotors have a common axis of rotation, the shafts being coupled together by means of a closely-fitting sleeve. The mounting details are held to close tolerances and care is taken in the assembly to ensure that the rotors run easily without binding. Phase shifts in the servo amplifier have been reduced to very small proportions by the use of negative feedback; the transformer, which matches the output stage of the amplifier to the controlling phase of the motor, is left untuned. The principal compon of the harmonic content of the servo error signal is the th harmonic, and its removal by means of a bridged-T fi circuit has proved to be an effective cure of the saturat problem. The mean value of the fundamental compon at standstill is removable from the output of the induct generator by the addition to it of adjustable in-phase a quadrature voltages; since the amplitude of the cyclic fluct tion of the standstill signal with rotor position is a sm fraction of the mean value, the use of compensating sour in this manner has proved to be satisfactory. The time ph of the generator output is restored by means of a simple circuit. The 50 c/s voltages required for the operation of velodyne are derived from the public power supply so t no difficulty arises from the dependence of the phase shift this circuit on the supply frequency.

DESIGN DETAILS

The design of the velodyne is now considered in m detail. Fig. 2 is the circuit diagram of a representat integrator; there are applications in which the inducti generator output signal is subject to various comput operations prior to its use as a feedback term, but the purp of the arrangement of Fig. 2 is the straightforward on evaluating the time integral of the input signal. The circ diagram has been simplified by the omission of the re circuits, which are required for the control of the integra and for its initial setting when it forms part of a compl computer. The 50 c/s input signal is applied to the summ arm R_1; the second arm accepts the feedback term from induction generator and is made adjustable, by means VR_1, for purposes of integrator scaling. The junction of summing arms is taken to the control grid of V_1, wh functions as a cathode-follower and ensures that the bridge filter circuit is fed from a low impedance source. It will observed that the filter circuit is directly coupled to the out of V_1; use of capacitative coupling gave rise to seri paralysis effects under conditions of transient overload s as may occur during the initial setting of the integrator, a was abandoned for this reason. The return path to earth

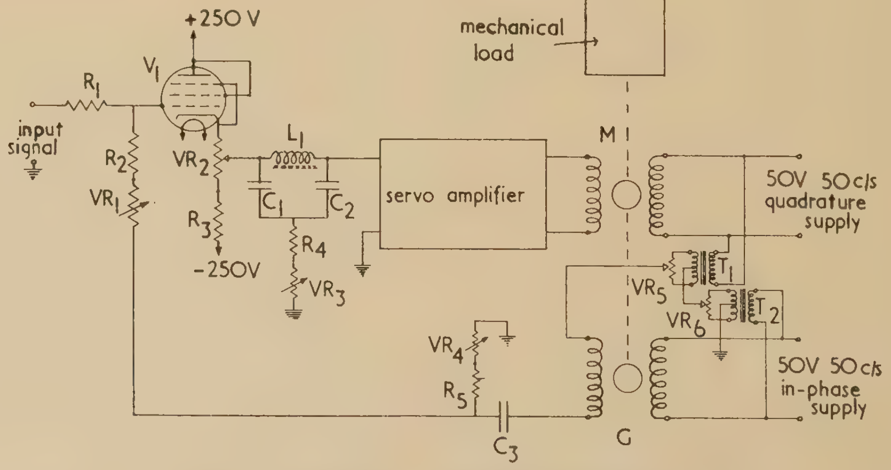

Fig. 2. Circuit diagram of representative integrator

R_1 = usually of the order of 1 MΩ; value is dependent on scaling requirements.
R_2 = 560 kΩ
R_3 = 33 kΩ
R_4 = 27 kΩ
R_5 = 2·7 kΩ

VR_1 = 50 kΩ
VR_2 = 5 kΩ
VR_3 = 10 kΩ
VR_4 = 5 kΩ
VR_5 = 1 kΩ
VR_6 = 1 kΩ

C_1 = 0·5 μF
C_2 = 0·5 μF
C_3 = 2·5 μF
L_1 = 4·5 H
T_1 = 50 V/0·25 V
T_2 = 50 V/0·25 V

V_1 = 6 AM 6
M = two phase induction motor, British Services No. 10743.
G = two phase induction generator, British Services No. 10877.

control grid of the input stage of the servo amplifier is L_1 and the cathode circuit of V_1, as it is undesirable to d the filter by providing a grid leak in the amplifier. In sequence of this, the cathode-follower output is taken n the potentiometer VR_2 which is adjusted to give a d.c. el of zero at the amplifier input grid.

n the filter circuit, the inductance L_1 is wound on a roxcube core and has a Q of about 30, this value repre- ting a reasonable compromise between the conflicting uirements of small phase shift at the carrier frequency manding a high Q) and freedom from serious mistuning ects at the rejection frequency arising from thermal and eing drifts in component values. The filter is tuned to ect 150 c/s signals by adjustment of L_1 (by means of a ntrollable air-gap) and VR_3. At the quoted value of Q, e phase shift through the filter at 50 c/s is about 1·4°. The ean value of the fundamental component of the generator tput at standstill is removed by the connexion, in series th the output, of in-phase and quadrature voltages derived from the potentiometers VR_5 and VR_6, these being energized from the small transformers T_1 and T_2. Fig. 3 depicts the manner in which the in-phase and quadrature components of the output at standstill vary with rotor position for a typical generator. It will be observed that the quadrature component exhibits an appreciably larger variation than does the in-phase component, but since it is ineffective in producing torque, the consequences are not serious. The removal of the mean quadrature component remains important as a means of combating saturation effects. The time phase of the generator output is restored in the circuit C_3, VR_4, R_5 (Fig. 2). The variation of phase shift of the generator output with rotational speed is negligible up to a certain critical speed, which is a function of the load on the generator; the component values in the phase-restoring circuit are chosen so as to achieve a maximum value of this critical speed.

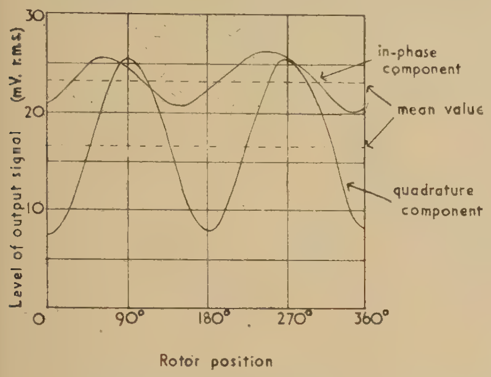

Fig. 3. Variation of generator output at standstill with rotor position

For clarity, the circuit diagram of the servo amplifier is drawn separately in Fig. 4. A pentode first stage (6AM6) is followed by a triode (one half 12AX7), the phase shift at 50 c/s introduced by the inter-stage coupling being about 3°. The triode stage is directly coupled through a neon tube (G50/1G) to the other half of the 12AX7 double triode, which functions as a phase-splitter. The output stage comprises two beam tetrodes (807) operating in push-pull Class A, transformer-coupled to the motor load. A stabilized 250 V supply is required for the first two stages and for the screen grids of the output valves; the phase splitter and the anodes of the output stage run off a 500 V unstabilized supply, the phase splitter being decoupled as shown in Fig. 4. Negative feedback is applied from the secondary side of the output transformer to the cathode circuit of the first stage, the amplifier gain of about 20,000 being thereby reduced to about 1000; there is a corresponding reduction in the overall phase shift at 50 c/s. Such an overall gain has been found to be great enough to reduce the errors in integration caused by Coulomb friction to quite negligible proportions, but it is not so great as to endanger the stability of the system as a whole.

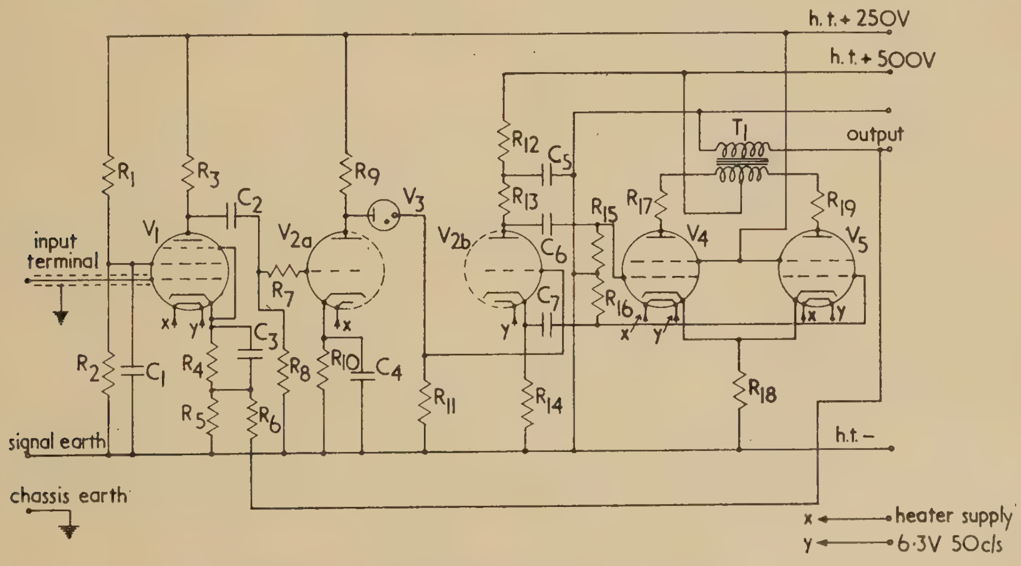

Fig. 4. Circuit diagram of servo amplifier

R_1 = 100 kΩ, ½ W
R_2 = 22 kΩ
R_3 = 560 kΩ
R_4 = 3·3 kΩ
R_5 = 100 Ω, 2%
R_6 = 100 kΩ
R_7 = 560 kΩ

R_8 = 560 kΩ
R_9 = 330 kΩ
R_{10} = 3·3 kΩ
R_{11} = 1 MΩ
R_{12} = 120 kΩ
R_{13} = 150 kΩ, 2%

R_{14} = 150 kΩ, 2%
R_{15} = 330 kΩ
R_{16} = 330 kΩ
R_{17} = 47 Ω
R_{18} = 270 Ω 6 W, 5%
R_{19} = 47 Ω

C_1 = 1 μF
C_2 = 0·1 μF
C_3 = 12 μF
C_4 = 12 μF
C_5 = 2 μF
C_6 = 0·25 μF
C_7 = 0·25 μF

V_1 = 6 AM 6
V_2 = 12 AX 7
V_3 = G50/1G
V_4 = 807
V_5 = 807

T_1 = 8 : 1 stepdown output transformer, 30 W rating.

All resistors are ¼ W, 10%, unless stated otherwise.

It now remains to describe the mechanical arrangement of the integrator. The several integrator units employed in the large computer already mentioned differ in detail amongst themselves as regards the value of the gear ratio between the motor-generator combination and the mechanical load, and the choice of computing elements (potentiometers, magslip resolvers and the like) comprising this load. But they possess certain basic constructional features in common, the most important of which are now briefly summarized. The mechanical components are installed on a base plate, $\frac{1}{4}$ in. thick, of Alclad aluminium alloy (to specification DTD 610 B), measuring 19 × $8\frac{3}{4}$ in., which is given additional rigidity by attaching to it a cast aluminium frame of rectangular shape having a wall thickness of $\frac{1}{4}$ in. and measuring 17 × $8\frac{3}{4}$ in., with a depth of $2\frac{1}{2}$ in. Wherever possible, the major components are spigotted into the base plate and carry their driving gears on hubs pinned to their shafts. Idler gears run on spindles attached to blocks dowelled to the base plate after they have been located to give the minimum of backlash consistent with smooth running. The "in-line" assembly of motor and generator units is depicted in Fig. 5. The units are spigotted into an open cylindrical member with flanged ends and their rotor shafts are coupled by means of a sleeve secured to them with grub screws. Port holes are provided in the cylinder to facilitate this stage of assembly. The electrical connexions to the motor are easily made since the terminals are at the free end of the motor; the generator terminals are not directly accessible and so a terminal strip is mounted on the cylinder, connexions being made from it to the generator during assembly. The motor is retained in the assembly by means of the usual magslip clamping ring held down with bolts screwing into the cylinder flange. The other cylinder flange retains the completed assembly on the mounting plate by means of pillars tapped at their ends. The assembly is open to the criticism that it calls for the alinement of four bearings, but no difficulties have been experienced on this account.

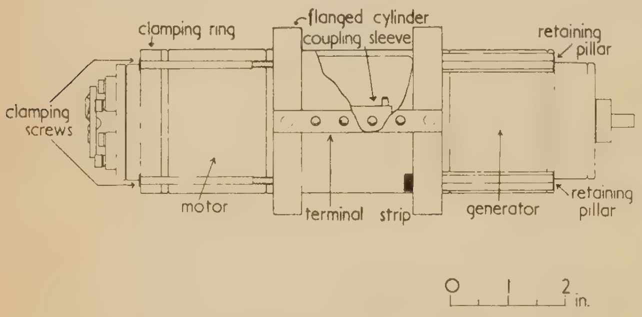

Fig. 5. Assembly of motor and generator

In addition to the conventional heater and h.t. supplies required by the servo amplifier, which do not merit detailed consideration, in-phase and quadrature sources of 50 c/s power at a level of 50 V r.m.s. are needed for the operation of the integrator. Quadrature excitation of the motor reference winding is necessary for the development of maximum torque since the amplifier output voltage is substantially in phase with the computing signal input to the integrator. These supplies are readily obtainable from the laboratory 50 V three phase supply, two lines of which give immediately an in-phase source; the voltage between the third line and neutral is in quadrature at a level of 29 V, and a step-up transformer is used to bring this up to the 50 V required to excite the motor.

PERFORMANCE

The quantities handled by the special-purpose comp for which the integrator was developed vary smoothly slowly with time. The choice of the comparatively carrier frequency of 50 c/s is therefore not disadvantage and the reduction of Coulomb errors in the integrations i greater importance than the achievement of high trans performance. The performance of a representative i grator, in which the mechanical load is a Colvern poten meter, type CLR 8205, driven through a reduction ratio 600 : 1, may be summarized in the following terms. minimum speed at which the system will run smoothly consistently is 3·5 rev/min at the motor shaft; the linea of the variation of motor speed with amplitude of the (stea input signal to the integrator is well maintained up 1600 rev/min, the greatest departures from linearity be ±5 rev/min. These departures are due mainly to the inhe errors in the output voltage/rotational speed characteristi the induction generator. Above 1600 rev/min, rather la errors are encountered and these are considered to be to the change of time phase of the generator output w rotational speed which sets in at and above this speed. Ab about 2300 rev/min, the errors become very large; t indicate the onset of saturation in the output stage of servo amplifier.

The steady-state frequency response of the integrator not been determined, but the effects of step-function chan in the level of the input signal to it have been studied osci graphically. The input signal changes were arranged to from zero to a level corresponding, in the steady state, t motor speed of 650 rev/min, and vice versa. Oscillogram the servo error signal show that the transition from the steady state to the other is substantially complete in ab 0·06 second. The servo amplifier is saturated for practic the whole of this time interval and the motor then produ the maximum acceleration of which it is capable. A ro estimate of this is obtainable from a knowledge of the ma mum torque developed by the motor (290 g-cm) and moment of inertia of motor (150 g-cm^2) and genera (54 g-cm^2). The acceleration is found to be 1400 rad/s^2; comparison, 650 rev/min speed change in 0·06 s is ab 1100 rad/s^2. The extent of the linear régime of the in grator may be estimated following a method described West.(3) Referring to Fig. 1, let the maximum signal wh can be applied to the input terminal of the servo ampli before saturation results be e'. Corresponding to this, difference between demanded generator output and act output is $\dfrac{R_1 + R_2}{R_1} . e'$, or in terms of speed, $\dfrac{R_1 + R_2}{R_1 K}$. where K is the slope of the generator output voltage/sp characteristic. Substitution of the values for the integra used in the experiment shows that saturation occurs if speed differs from that demanded by more than 40 rev/min. should be noted that saturation effects do not detract fr the performance of the integrators; in fact, saturation ensu that a sudden large change in demanded speed is assimila by the system as rapidly as possible.

TEMPERATURE EFFECTS

The output of the induction generator has a temperat coefficient of −0·02 V/° C at a speed of 1000 rev/min, output level at this speed being 7 V r.m.s. The results alrea quoted for the linearity of the motor speed/input sig characteristic of the integrator were observed on a unit wh allowed to warm up thoroughly, with all power supplies ched on, under steady conditions of ambient temperature, ore measurements were made. They are therefore usive of errors due to temperature effects. In day-to-day ration of the integrators, these effects can introduce ificant errors of scaling. Subsequent to the developments cribed in the present paper, the authors' colleague, Mr. W. Righton, has shown that temperature errors can be uced to very small proportions by the use of a thermistor orm part of the summing arm which accepts the output al from the generator. The thermistor is mounted on the erator casing and therefore shares its environment. Since temperature coefficient of resistance of the thermistor is ative, the effect on the feedback signal of the change of erator output with temperature will be offset by a change he resistance of the thermistor and, provided the propor- of thermistor resistance to total resistance in the feedback arm is chosen correctly, effective temperature compensation may be obtained.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Williams, F. C., and Uttley, A. M. *J. Instn. Elect. Engrs*, **93**, Part IIIA, p. 1256 (1946).

(2) Langham, E. M. *Automatic and Manual Control*, ed. Tustin, A., p. 535. (London: Butterworths Scientific Publications, 1952.)

(3) West, J. C. *Textbook of Servomechanisms*, p. 116. (London: English Universities Press Ltd., 1953.)

The flash photography of a deep field of view

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An optical arrangement for the photography of deep fields of view is described. It involves the illumination of successive strips of the object space and the use of a weak auxiliary lens of variable focal length. The variable lens refocuses in about 2 ms.

the photography of tracks in a deep Wilson cloud chamber encounters serious difficulties in providing adequate mination. A practical solution to these difficulties has n found by using a novel system of refocusing a camera ective. The method may be applicable to other problems photography of deep fields of view, and therefore the eral problem is discussed before this particular solution is cribed.

THE OPTICAL PROBLEM

f an aberration-free lens, having a ratio of focal length to meter A, is used to image a field of view with finite depth, size of the image of a point object lying outside the focal ne increases with A because of diffraction, but decreases h A because of depth of field. The optimum value of A, t for which the circles of confusion due to these effects are al, is given approximately by

$$A = \frac{1}{2M}\left(\frac{d}{\lambda}\right)^{\frac{1}{2}} \qquad (1)$$

being the ratio of object to image size, d the total depth of d, and λ the wavelength of light. This permits the olution of two point objects with separation δ where δ given approximately by

$$\delta = (\lambda d)^{\frac{1}{2}} \qquad (2)$$

us the maximum resolution possible over the depth of the d is limited by d.

he calculated optimum value for A is often large. In the cific problem with which the authors were confronted it twenty-eight, and for such large focal ratios the resolution camera lenses is, in fact, good enough to treat them as rration-free.

In practice the optimum value of A may be so large that it is uneconomical or impracticable to get enough light intensity to record the image. A larger aperture must then be used and the resolution is determined solely by depth of field. The focal ratio required for a given resolution is linearly proportional to d, the intensity of light required is proportional to d^2 and may become prohibitively large for large d.

These difficulties can be reduced if it is possible to illuminate slices of the object space in turn by discharge lamps and to refocus the objective between discharges. This can be accomplished by means of an auxiliary lens of variable power. The authors have used a water lens bounded by glass plates which are bent by changing the effective volume of the water by magnetically-operated bellows. The illuminating system used when this idea was applied to a large cloud chamber is shown schematically in Fig. 1.

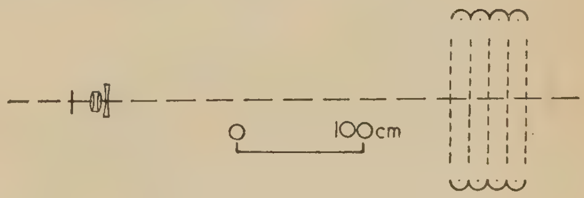

Fig. 1. Schematic drawing of optical arrangement

THE METHOD OF REFOCUSING

The optical system consists of a conventional camera, having an $f/5{\cdot}6$ lens of 12·7 cm focal length, with a weak variable focus lens (Figs. 2 and 3) placed directly in front of it.

The weak lens consists of a sealed vessel of water with two optically-polished glass windows, 1·5 mm thick. The positions of the windows are defined by rigid brass retaining rings *g*. The surface of each brass ring in contact with the glass has a ground flat edge about 0·1 mm wide *h*. The glass seals to the brass vessel on soft rubber O-rings *k*, compressed as little as possible to avoid distorting the glass, and located directly under the ground edges *h* of the brass rings. The vessel connects to three $\frac{3}{8}$ in. diameter brass sylphon bellows *e* and to a 6 in. length of 6/1000 in. inner diameter stainless steel capillary tube *l*. The position of the bellows is defined in compression by the armature *b* of a lamina magnetic circuit, and in extension by an adjustable stop The working travel of the bellows is about 0·05 cm. T capillary tube leads to an unsealed water reservoir *m*. T allows a leak to atmospheric pressure with a "time consta of a few seconds, ensuring that the focal length is unaffec by changes of temperature.

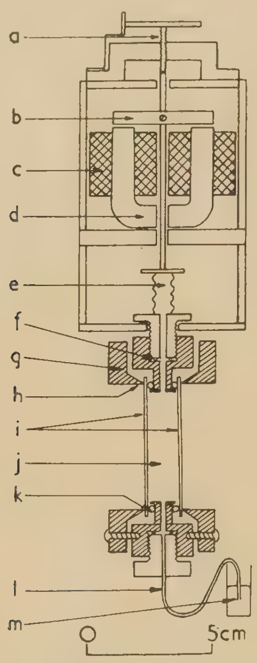

Fig. 2. Side section of variable focus weak lens

a, adjustable stop; *b*, moving armature; *c*, coils; *d*, laminated magnetic circuit; *e*, sylphon bellows; *f*, rubber washer seal; *g*, brass retaining ring; *h*, ground edges; *i*, glass windows; *j*, distilled water; *k*, O-ring seal; *l*, capillary tube; *m*, water reservoir.

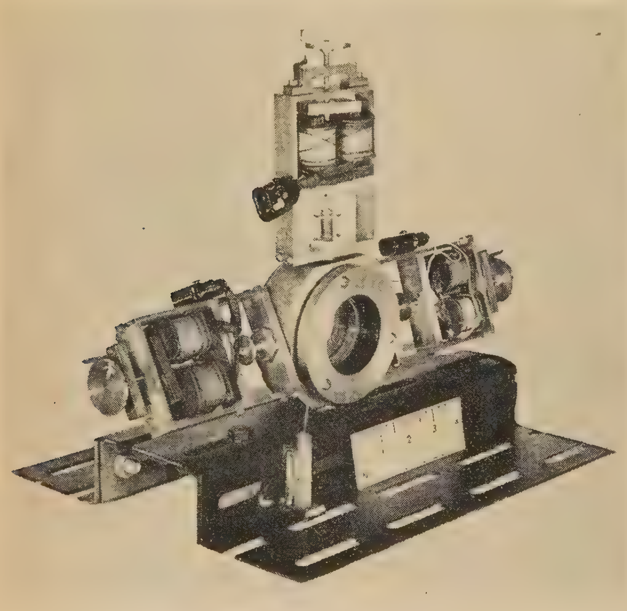

Fig. 3. The variable focus weak lens

Before each photograph the water lens is set with all magnets energized (passing about 10 mA current) and optical system focused on the section of the chamber il minated by the front pair of lights. This pair of lights flashed, then the first bellows is expanded, thus refocus for the second pair of lights, and so on. After the fou pair of lights has been flashed the magnets are reset pulsing a current of around 35 mA through them.

APPLICATION TO CLOUD CHAMBER PHOTOGRAP

A system for photographing a region of 90 × 90 × 60 c inside a Wilson cloud chamber was required. The region illuminated by four quartz discharge lamps and cylindri parabolic mirrors at each side of the chamber (Fig. Condenser banks with a total stored energy of 6000 Jou are used, and because of faintness of illumination the reso tion is limited by depth of field.

Two conditions had to be met by the lens system in t application. Firstly the time for each refocusing operat could not be greater than a few milliseconds. Secondly, a lateral displacement of the image had to be small.

This second condition requires that the refocusing sho leave the position of the nodal points unaltered. If th move, a straight track at the side of the chamber inclined the focal plane is recorded as four parallel but displac segments. Since the beams from the lights overlap a f centimetres, the section of track in the region of overl would also appear blurred. The authors' method of refocus shifts the nodal points about one fourth as far as they wo move were refocusing to be achieved by shifting the cam lens with respect to the film. With the present system, the least favourable angle of view, the image displacem of a fixed object point after one bellows expansion is abo 15 μ, which is just tolerable.

PERFORMANCE

The most striking advantage of the system is the gr saving in the energy stored in condensers for the lights. I conventional optical system requires a capacitance of farads per lamp with a focal ratio *A*, then with refocusin focal ratio A/n will suffice for a similar resolution with focus positions. Thus a capacitance of C/n^2 (6000 J) is u to obtain a quality of image otherwise requiring C far (96 000 J). The use of a large stored energy is not o prohibitively expensive, but also destroys the discharge lam very rapidly.

TIME OF OPERATION

The measured time for the expansion of a bellows is 2 (Modified design could reduce this nearer to the ultim limit of 100 μs set by the speed of sound in water.) Beca of the characteristics of the discharge lamps the total ti required for a photograph with this refocusing system appreciably less than that which would be required with conventional system. The Xenon filled lamps have a rge time, t seconds, proportional to the capacitance, C ads, discharged through them, where $t = 5C$ seconds. ce the lamps are flashed in sequence a time $t' = n.(5C/n^2)$ $5C/n$ is required for the condenser discharge compared h a time $5C$ in a conventional system. For this appli- ion t' is around 12 ms and the delay in moving the lens d only add 6 ms to this. For identical performance the nventional system requires 48 ms.

RESOLUTION

The resolution of the system has been examined at angles to 15° off axis. With static deformation of the lens, servation with a microscope shows a resolution of better t 5 μ in the image focal plane. There was some light tside this image due to imperfect figuring of the glass ndows. It did not appreciably affect the definition obtained practice. Dynamically the resolution is at least as good as μ, the resolution of the film used.

RELIABILITY

The total increase in the bellows volume is only 0·1 cm^3. It is therefore important that there shall not be more than about this volume of undissolved air in the system when it is filled with water. Furthermore, since its pressure drops by about 1/20 atm when expanded, it is important that air shall not leak in, for the shift of focus is altered 5% by an addition of 0·1 c.c. of free air. The system is evacuated to around 0·01 mm of mercury pressure, tested for leaks, and completely filled with freshly boiled distilled water. With these precautions the lens has worked without requiring adjustment for three months—undergoing around 3000 expansions. There seems to be no difficulty with the water "outgassing."

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A simple instrument for the periodic application of controlled bi-axial strains

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This instrument produces harmonically varying strains in a thin layer of a test material and controls in two dimensions the frequencies, amplitudes and phases. Weissenberg's method of a flexible boundary is employed to obtain homogeneous strain and a uniform break-up pattern when fatigue failure is approached. The specimen adheres to the surface of a rubber sheet which is extended in two directions by sets of parallel strings fastened to sliding carriages. The carriages follow circular cams, one directly and one through a lever. The cams are interconnected by a chain and rotated in rigidly located bearings by hand or motor. Any phase difference is readily set by positioning the chain wheels, and any ratio of amplitudes by shifting the fulcrum of the lever. A ratio of frequencies can be selected by choosing appropriately sized chain-wheels. To illustrate the applications, the fatigue of powders under various testing conditions is described and the emergent break-up patterns are discussed.

INTRODUCTION

ne reason for the existence of so many mutually con- cting theories about the criteria of mechanical failure of atter$^{(1, 2, 3)}$ is the lack of comprehensive experimental idence due to the limitations imposed by conventional sting methods. In order to supplement standard investiga- ons and widen the range of controlled test conditions eissenberg has introduced$^{(4)}$ a new testing method employ- g deformable boundary members—sheets, tubes, etc.—to ansmit a deformation to the test material by contact over main plane of imposed strain. This procedure extends the nge of materials that can be tested including powders and stes; it improves the control of strain applied to the aterial particularly when approaching failure produces homogeneities, since it does not rely on the test specimen elf to transmit the imposed deformation; it also enables e distribution of stress to be measured.

A more detailed discussion and applications of the method straining by means of a flexible boundary have been given Jobling and Roberts.$^{(5, 6)}$ These authors discuss the gular patterns obtained before rupture and in particular the observed directions of the break-up lines and their relation to the strain and stress geometry.

Harmonically varying deformations are particularly interesting among deformations leading to rupture. They produce a break-up pattern of higher regularity and at lower amplitudes than do continuously increasing deformations, and they are related to fatigue failure an understanding of which is of great practical importance. Any harmonic deformations in two directions can be obtained by controlling the two frequencies, two amplitudes, and the relative phase difference. As long as the amplitudes are small their absolute values are not expected to be critical when the directions of discontinuities are determined, and only the ratio of the two amplitudes is important. Jobling and Roberts$^{(5, 6)}$ produced two discrete ratios of amplitude and could also make the ratio vary continuously, but their devices did not provide for an arbitrary ratio constant over a large area. The two controlled deformations in their experiments were either exactly in phase or exactly out of phase. In order to supplement their work it has been felt desirable to design an instrument that would produce, in a flexible boundary member, harmonic deformations in two directions, the phase difference and the ratio of amplitudes of which could be changed at will. Such an instrument would serve to provide the wide range of conditions necessary for experiments on the factors influencing the development of break-up patterns, and it could be used for any other experiment in which controlled strains must be produced in the material.

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* On leave from the C.S.I.R.O., Australia.

DESCRIPTION OF THE INSTRUMENT

The instrument illustrated in Fig. 1 consists of a frame, a straining system, and a driving mechanism. The frame provides the base for the location of the functional parts and is made up of four steel bars, each about 30 cm long, welded to form a square. The corners are supported to lift the frame about 3 cm above table level.

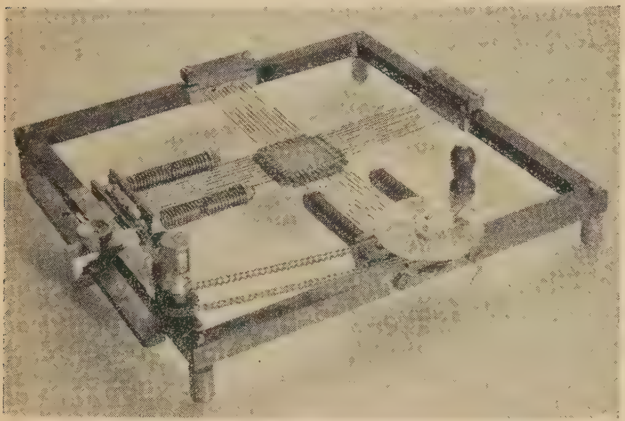


Fig. 1. View of the straining instrument

The straining system serves to apply to the test specimen a homogeneous strain depending on the movement produced by the driving mechanism. A rubber sheet 4 cm square acts as the flexible boundary to which the material adheres. A margin around the edges of the sheet is cut into strips as in Treloar's$^{(7)}$ experiments. Each strip is gripped by a metal clamp [Fig. 2, detail (3)], the top jaw of which is wedge-shaped and flush with the surface of the rubber when pulled by an attached cotton string. Two adjacent sets of strings are fastened to the frame and the other two sets to carriages S_1 and S_2 sliding on steel rods. They are clamped between soft rubber lining and can thus be individually adjusted to provide uniform tensile bias to the rubber.

The driving mechanism (Fig. 2) is designed for the production of harmonic motions of various frequencies, amplitudes, and relative phases. The axes of two circular cams C_1 and C_2 are connected by a chain and rotated in the frame, either by hand or by a motor. The cams drive the two sliding carriages S_1 and S_2, one directly, the other through a lever. Compression springs of adjustable deformation provide the returning force.

One chain-wheel is fastened to the shaft of cam C_1 by a screw [Fig. 2, detail (2)]. After loosening the screw the operator can move the handle and chain rotating the other cam while cam C_1 and the attached Perspex disk remain stationary. The screw is fastened again when the line marked on the handle coincides with the required phase angle marked on the disk.

The pivot of the lever L joins two jaws [Fig. 2, detail (1)] clamped to the frame. By moving the jaws to an appropriate position the ratio of the two lever arms can be set and thus the movement of the carriage S_2 increased or reduced at will. A calibrated scale indicates the lever ratio. alternative pivot holes are provided to avoid excessive le of the lever beam.

RANGE AND ACCURACY

The eccentricities employed were of the order of ha millimetre giving over a sheet length of 4 cm an elonga ratio of about 10^{-2}. The lever can be set to reduce amplitude to any value down to zero, or to increase it u threefold. Larger eccentricities may be used but an incr in overall size of the instrument is recommended if amplitu above 2 mm are required, because the force of the sprin the model described would vary considerably during a c and cause excessive wear on the cams. For amplitu below 2 mm the angle of the lever to the frame varies by than 1·5° from its mean and the distortion this varia causes is negligible.

The lower limit of amplitudes that can be satisfacto employed is determined by clearances and fitting of moving parts. A good fit between the rods and the slic carriages is particularly important and the shafts on carriages have been made as long as practicable to minim rocking which would distort the strain field. The amplit of the harmonic deformation did not vary measurably f one side of the rubber sheet to the other, when the distar between opposite edges were measured in the centre an the corners by means of a measuring microscope sensi to 10^{-2} mm.

The position of the clamps around the edge of the rub and the biasing extension by each string need not be with great accuracy since only the additional harmo strain is transmitted to the layer of test material. A cla displaced by $\frac{1}{2}$ mm will cause little more than one per c distortion of the strain in the test material.

The textile strings are considered rigid compared w the rubber. Even if their extension were significant it wo only reduce the strain amplitude in the rubber without a first order, distorting the field; when great precisio required, steel wires may be used instead of the stri Uniformity of the strain field on the surface of the material relies on the homogeneity of the rubber. corner of the rubber sheet remains stationary with resp to the frame. The advantages of a stationary centre w considered insufficient to warrant the more elaborate des necessary. The differences in elongation due to the di gence of the strings during a cycle are negligible.

The position of the phase dial is set correctly for direction of rotation and should occasionally be recheck With the chain drive used, reading the phase shift m closely than to the nearest five degrees was not attempted

Optimum compression of the springs depends on extensibility of the rubber; their restoring force should sufficient to compensate for the forces in the stretched rub and to overcome any friction, but in order to avoid wea should not be increased more than necessary.

Various ratios of the frequencies of rotation of the ca can be introduced by changing the sizes of the chain-whe The maximum frequencies suitable for the model descri is of the order of 10 c/s but with appropriate pivot bearings and a reduction in the mass of the moving pa this can be considerably increased.

APPLICATION

The instrument has been used to produce break-up patte in powders subjected to various strains. The ratio of

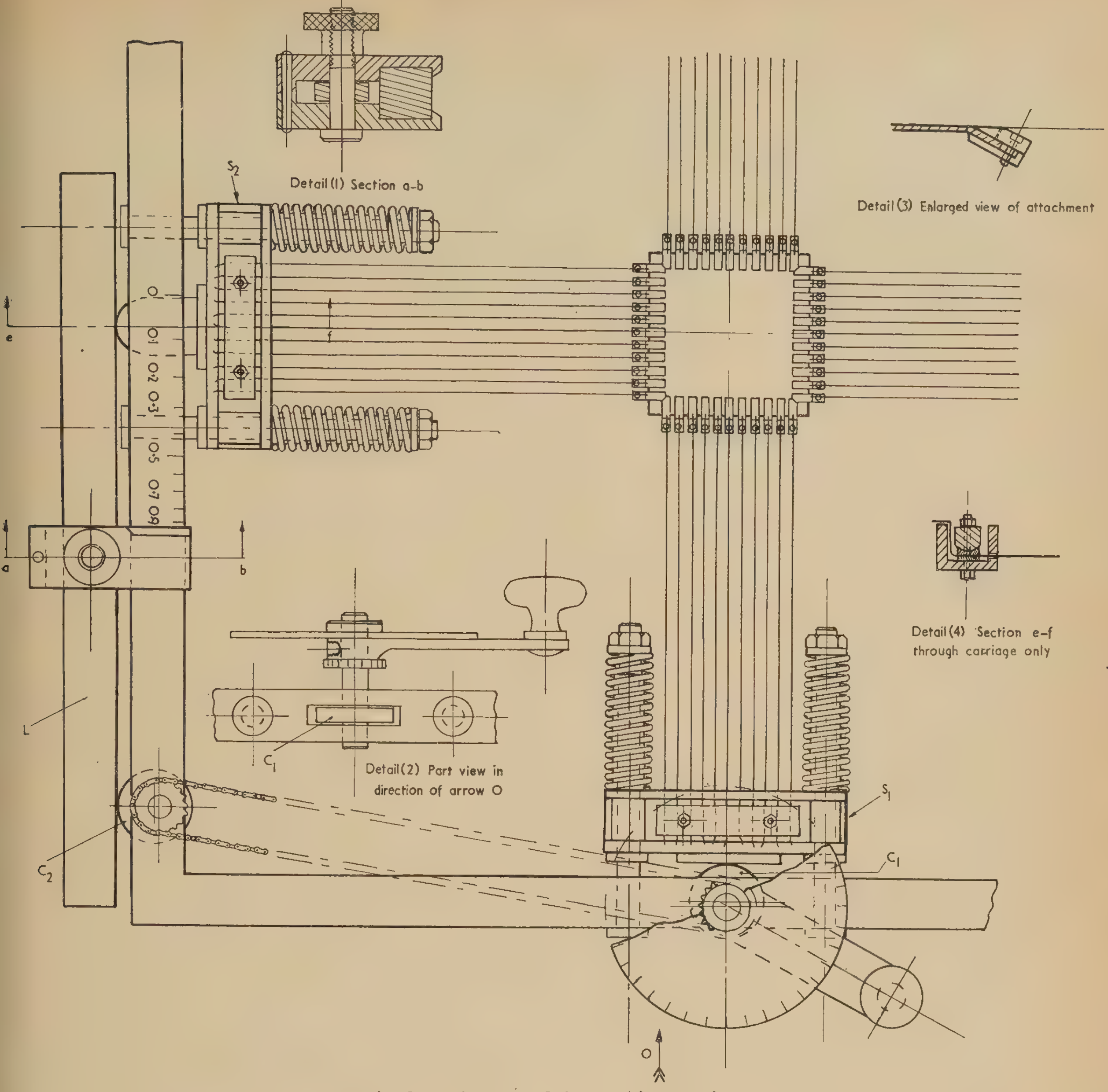
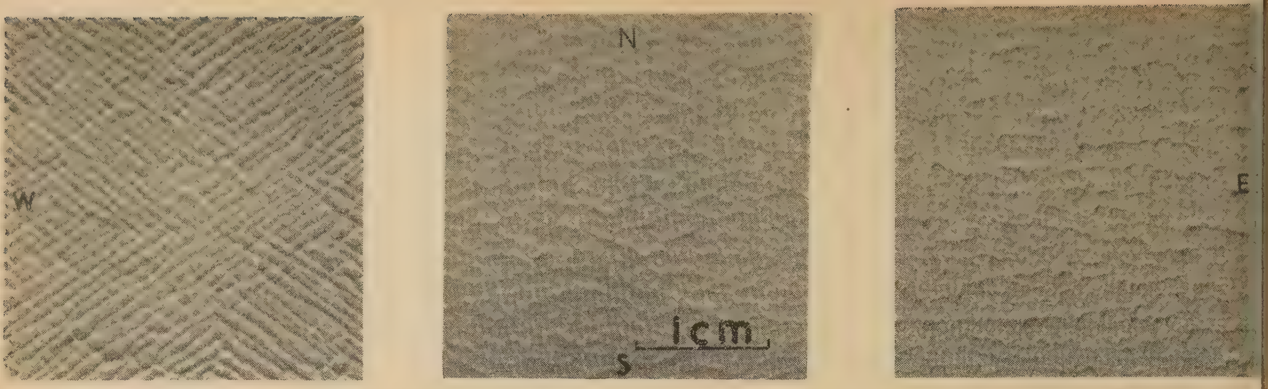

S2
Detail (1) Section a–b
Detail (3) Enlarged view of attachment
e
f
O
0·1
0·2
0·3
0·5
0·7
0·9
a
b
Detail (4) Section e–f through carriage only
L
C1
Detail (2) Part view in direction of arrow O
S1
C1
C2
O

Fig. 2. Diagram of the working portion

nplitudes was set and both cams were put into their mean sition. A supporting table was placed underneath the bber sheet, the powder sprinkled on the sheet and spread a plate riding on rails an adjustable distance above it provide uniform height of powder. After removal of the reading accessories the phase difference was set and several ndred strain cycles were imposed until a well defined ttern appeared on the top surface of the powder. When raining was continued further, cracks appeared along the lges in the pattern.

Fig. 3 shows break-up patterns observed in dry cornflour read to a thickness of 0·6 mm and taken through 200 cles. With a phase difference of 180° between the two utually perpendicular vibrations [Fig. 3(*a*)] a sharp regular ttern develops, the directions of the flow-lines being termined by the ratio of amplitudes, and the distance tween lines by the thickness of the layer. Similar patterns re obtained by Jobling and Roberts.(5, 6) When the smaller amplitude leads by 135° [Fig. 3(*b*)] a similar but less regular pattern appears. The ratio of the two elongations varies with time but during a large part of each half-cycle it remains in the close neighbourhood of the amplitude ratio $-\frac{1}{2}$ which determines a preferential direction. When the lead of the smaller amplitude is reduced to 90° [Fig. 3(*c*)] a different type of break-up occurs. The flow-lines are perpendicular to the principal directions of elongation. A qualitatively similar pattern results from further reduction of the phase difference, in particular when the two deformations are in phase.

Experiments of this nature on powders are of particular value if analogies can be drawn with the behaviour of more rigid materials. The striking similarities in flow-lines of widely different materials pointed out by Jobling and Roberts(5, 6) supports such analogies. The instrument can also be used for the investigation of the behaviour of pastes and thin polymer and metal films. With a more rigid



(*a*) (*b*) (*c*)

Fig. 3. Fatigue patterns in cornflour. Strain amplitude N–S twice that of E–W
(*a*) the two strain components 180° out of phase; (*b*) the smaller vibration leading by 135°; (*c*) the smaller vibration leading by 90°.

boundary material, e.g. steel, the same principles can be applied to the testing of a great variety of materials.

ACKNOWLEDGEMENTS

Professor (emeritus) K. Weissenberg suggested the need for an instrument fulfilling the above requirements and the author wishes to express his thanks for the encouragement received and for helpful discussions. Mr. J. Pratt built the instrument and his suggestions on construction were appreciated.

REFERENCES

(1) Mehldahl, A. *Brown Boveri Rev., Baden*, **31**, p. 260 (1944).

(2) Orowan, E. *Rep. Progr. Phys.*, **12**, p. 185 (1948–49)

(3) Nadai, A. *Trans Amer. Soc. Mech. Engrs* [APM], p. 111 (1933); also *Theory of Flow and Fracture of So* 2nd Ed., p. 207 (New York: McGraw-Hill Book Inc., 1950).

(4) Weissenberg, K. *Bull. Brit. Soc. Rheology*, No. p. 6 (1955).

(5) Jobling, A., and Roberts, J. E. *Rheology*, Part 2, Eirich (New York: Acad. Press, 1957).

(6) Jobling, A., and Roberts, J. E. *Brit. J. Appl. P* (in the press.)

(7) Treloar, L. R. G. *Proc. Phys. Soc.* [*London*] **60**, p (1948).

An automatic quartz-fibre electrometer

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A quartz-fibre electrometer with ancillary equipment is described, whereby an average rate of change of potential may be determined with probable errors of about ±0·2 mV in the change of potential, and ±0·02 s in the measurement of time. An instrument for automatic recording of β-activity within the range 0·04 to 30 μc is described in detail with experimental results.

The quartz-fibre electroscope is a simple, robust instrument which has the advantage that no electronic circuit errors are introduced into a measurement of radioactivity. The time taken for the charge on an ionization chamber to leak away owing to ionizing radiations is directly measured by visual observation of the movement of the fibre. Several automatic methods have been used to remove human timing errors and increase the versatility of electroscopes[(1–4)]; in the present instrument the quartz fibre, optical system and electronic circuits have been further developed to increase the range and accuracy of ionization current measurements.

The utility of a visual electroscope is limited by the long time required to obtain a measurable deflexion at low levels of ionization current, and by the difficulty of accurate measurement of the short transit times obtained when the current is high; both these limits are extended by photoelectric detection of the fibre position and by use of electronic timing circuits. If the error of measurements of rate of change of potential is made small enough, the time spent measurement of activity may be reduced to that requi for the collection of a statistically significant number α- or β-particles. The instrument which is described can be used to compare β-active sources in the range 0 to 30 μc with an accuracy which is, in practice, limited by changes in ionization efficiency of the ion chamber. method is applicable to other types of electroscope, and instrument can be associated with a printer to record repea measurements of the time taken by the ion chamber poten to change by any amount from a few millivolts up to 50 V

IONIZATION CHAMBER

The instrument, which is shown in Fig. 1, is a developm of the visual TQQ electroscope[(5)] which was designed Carmichael for measuring strong β-emitting sources, adapted by Bartholemew and others[(1)] for automatic plott decay curves. The radioactive source is surrounded by r at the centre of a hemispherical collecting electrode of 5 cm dius with a solid angle for β-particle collection which is ear to 2π. The instrument is similar in principle to the araday gold-leaf electroscope, since the potential which eflects the index is also used to collect the ions formed. rovided that the insulation is good, and apart from the fects of gravity and shock, the position of the fibre is anged only by ionizing radiations (there is a small temerature effect which is discussed below).

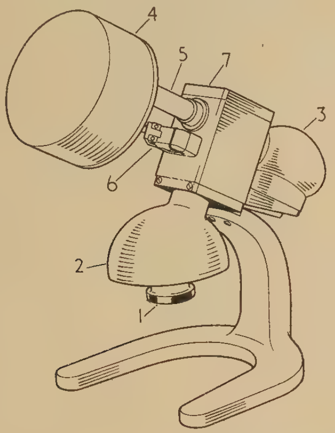

Fig. 1. Ion chamber and electrometer

(1) source holder; (2) ion chamber; (3) lamp housing; (4) photoelectric detector; (5) focusing eyepiece and aperture in viewing tube; (6) connexion to electronic unit; (7) housing for quartz-fibre charging relay and insulated support for collector electrode.

The ion chamber is used here as an integrating detector hich does not respond separately to each ionizing event, ut collects the total ionization over a period of time. An utomatic timer and a two-level potential threshold detector used to measure the rate of fall of chamber potential.

ELECTROMETER

Quartz-fibre electroscopes can now be made very compact. t is easy to adapt them for comparison of two potentials, either of which is near earth, and the optical method of eading the potential difference introduces no leakage.

In previous designs of automatic electroscope, separate ptical paths determine the start and finish of the sweep time. n practice, use of two apertures is difficult as the fibre must e in focus and correctly positioned relative to both. An lternative method has therefore been adopted in which the optical path and fibre index position are the same at the beginning and end of the sweep. This permits the use of a single aperture which overcomes the above difficulties and improves definition, while the edge errors, being now equal, are eliminated by subtraction. The method is shown simplified in Fig. 2 and it will be seen that a direct potential change is applied to the normally earthed side of the electroscope through *RLB* immediately after the timed sweep has begun. The change of potential may have any magnitude from a few millivolts upwards, and is only limited by the extra charging potential the ion chamber can withstand.

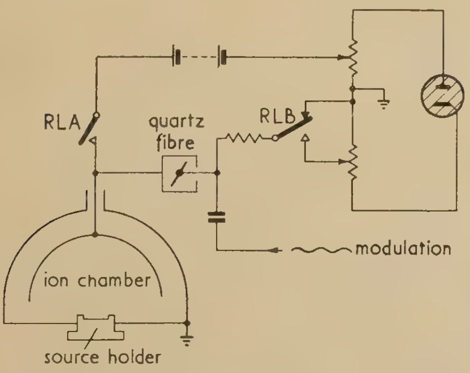

Fig. 2. Schematic of electrometer circuits

One advantage of the above arrangement is that the effective deflexion sensitivity of the quartz fibre need not be linear, since its position is detected only at one point in its range of movement, as shown in Fig. 3. Advantage is taken of this to obtain high sensitivity near this point. Another advantage is that since the sweep amplitude is determined by a direct potential, rather than by the separation of two apertures, simple automatic methods may be used to adjust the sensitivity of the instrument to suit unknown samples over a very wide range.

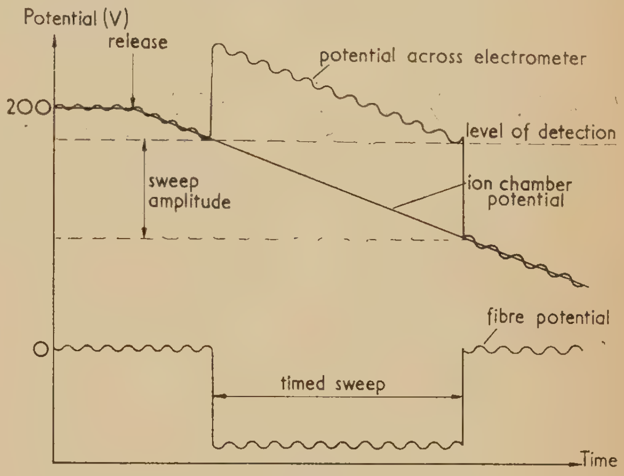

Fig. 3. Potential wave forms

SENSITIVITY AND ACCURACY

The sensitivity of the ionization chamber within the β-particle energy range 0·5 to 4 MeV is about 350 counts per mV and is reduced to about 500 counts per mV by the added capacity of the electrometer. The drift in potential on the ion chamber due to electrical leakage and natural radiation is referred to as the background of the instrument. This background measures about 1 mV/min and it determines the smallest β-source which can be accurately measured.

The ionization current produced by a β-source of 0·04 μc is about one hundred times the background, and causes a rate of change of potential of 100 mV/min on the insulated electrode of the ion chamber. Since the error of measurement of fibre index position is about ±0·2 mV (see next section) the error of measurement of this potential change is ±0·2% for a measuring time of 1 min. This error is small when compared with the statistical fluctuations in source disintegration rate measured repeatedly over the same period. The upper limit for accurate measurement of activity is reached when the time for a deflexion of 50 V is reduced below about 20 s (equivalent to 30 μc). The timing error of ±0·02 s then becomes significant, although it can be reduced by averaging repeated measurements.

ACCURACY OF POTENTIAL MEASUREMENT

Unless a very small sweep is selected, the error of measurement of potential change is small compared with the statistical fluctuations of disintegration rate. The error has been measured by repeatedly reading the time taken for a weak β-source to cause a deflexion of 5 mV. For periods up to $\frac{1}{4}$ min the standard deviation of a time measurement from the average of a large number of readings is ±4%, equivalent to ±0·2 mV, and this figure is increased to ±6% (±0·3 mV) when the mains supply is altered by 10% upwards or downwards during the time of sweep.

CHARGING THE ELECTROMETER

The ionization current is measured by the time taken for the total ion chamber capacity to discharge through a predetermined potential.

The chamber is charged by closing relay *RLA* of Fig. 2, which makes connexion between the highly insulated chamber electrode and a source of charging potential. The potential left on the chamber soon after opening the relay differs from the charging potential on account of the imperfect connexion made at the moment of break, the change in strain on the electrode insulator and change in capacity as the switch opens. All these effects are reduced by using very fine gold wires for the relay contacts and by screening the moving armature. There remains, however, an uncertainty of about ±10 mV in the potential left on the chamber immediately after the relay opens. To eliminate the effect of this variation, the chamber is charged to a potential about 100-mV above that at which the fibre index appears at the aperture, and commencement of the timed sweep is delayed until this overlap occurs for the first time, as shown in Fig. 3. Since negligible current is required, the charging potential may be conveniently obtained from a 180 V battery in series with a small adjustable source of potential.

THE QUARTZ-FIBRE INDEX

First experiments were made with a hair-pin cantilever of gilded quartz-fibre and with this there was an uncertainty of about 6 mV in the measurement of potential change, equivalent to a fibre movement of a quarter wavelength of the light source. A similar type of fibre is used in pocket radiation dosimeters, and although extremely rugged it is also very responsive to vibration. This does not matter in visual electroscopes but is disastrous in automatic instruments if the circuits are to be designed for a wide range of sweep rate.

A Lindemann type of torsion suspension was adopted which is very much less responsibe to shock. As shown in Fig. 4, the torsion fibre is fixed at both ends under tension so that the centre of rotation of the index is fixed and the movement of the index is observed at one end. By careful design of the electric field distribution a deflexion sensitivity of 1 mm/V was obtained over a narrow range of movement of the fibre index and this was made to correspond to the aperture position for a potential of 200 V. The potential required to overcome the torsion of the suspension changes less than one part in a million during the time of measurement, and its drift is small compared with the background of 1 mV/min.

A filter on the light source, with cut-off at 7500 Å (Chance type ON20) increases the optical accuracy by eliminating longer wavelengths and reduces local temperature rise of the fibre. This is more pronounced with the hair-pin type of fibre, the temperature of which is otherwise raised about 120° C by lamp radiation, causing a deflexion error which varies with the power supplied to the lamp. The effec insignificant with the torsion suspension, since the illumina index is not part of the suspension.

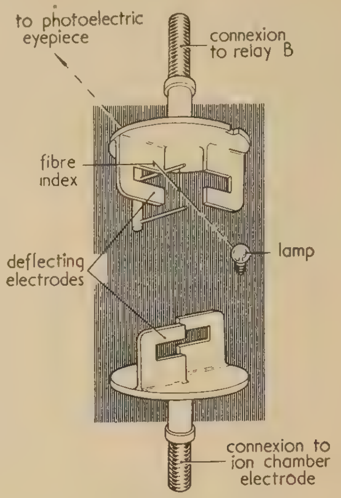

Fig. 4. Quartz-fibre torsion suspension and deflecti electrodes (exploded view)

MEASUREMENT OF FIBRE INDEX POSITION

The change in the ion chamber potential is equal to voltage which must be fed back to the low potential sid the electrometer in order to keep the fibre index in a position. This position is determined by the amount overlap between the magnified fibre image and a fixed ap ture. There is a reduction of about 40% in the light fall on the photocathode when the fibre image completely ov laps the aperture. The degree of overlap must be measu with great certainty and this requires that a very small cha in light intensity be detected.

Very small, slowly changing, shadows cannot be detec reliably with a normal photomultiplier and lamp system they cannot be distinguished from changes in brilliance of lamp and of sensitivity and gain of a photomultiplier. photometer is therefore used, based on a circuit of Coo Yarborough and Whyard,(6) which is insensitive to sl changes of light intensity but which responds to more ra changes. The fibre shadow is made to flicker by adding small amplitude alternating potential at 50 c/s to the l potential side of the electrometer, as shown exaggerated Fig. 3. This modulation vibrates the fibre with an amplitu equivalent to 30 mV deflexion and as the shadow approac the aperture its flicker is amplified by the photometer.

TIME MEASUREMENT AND PHOTOMETER

The range of times to be measured may extend from a f seconds when measuring β-sources in the region of 30 μc, several hours when checking background. A digital counti method is used to cover this range in which time is measu in units of 1/50 s up to 1 million digits (about 5 h). Suita waveforms are derived from a tuning fork 50 c/s oscilla (Muirhead type D418 D) and these are applied to the t guides of a Dekatron scaling tube, as shown in Fig. 5, whi is followed by a second Dekatron driving an electromechani register.

Since the tuning fork frequency is stable to fifty parts p million, the only significant error of time measurement

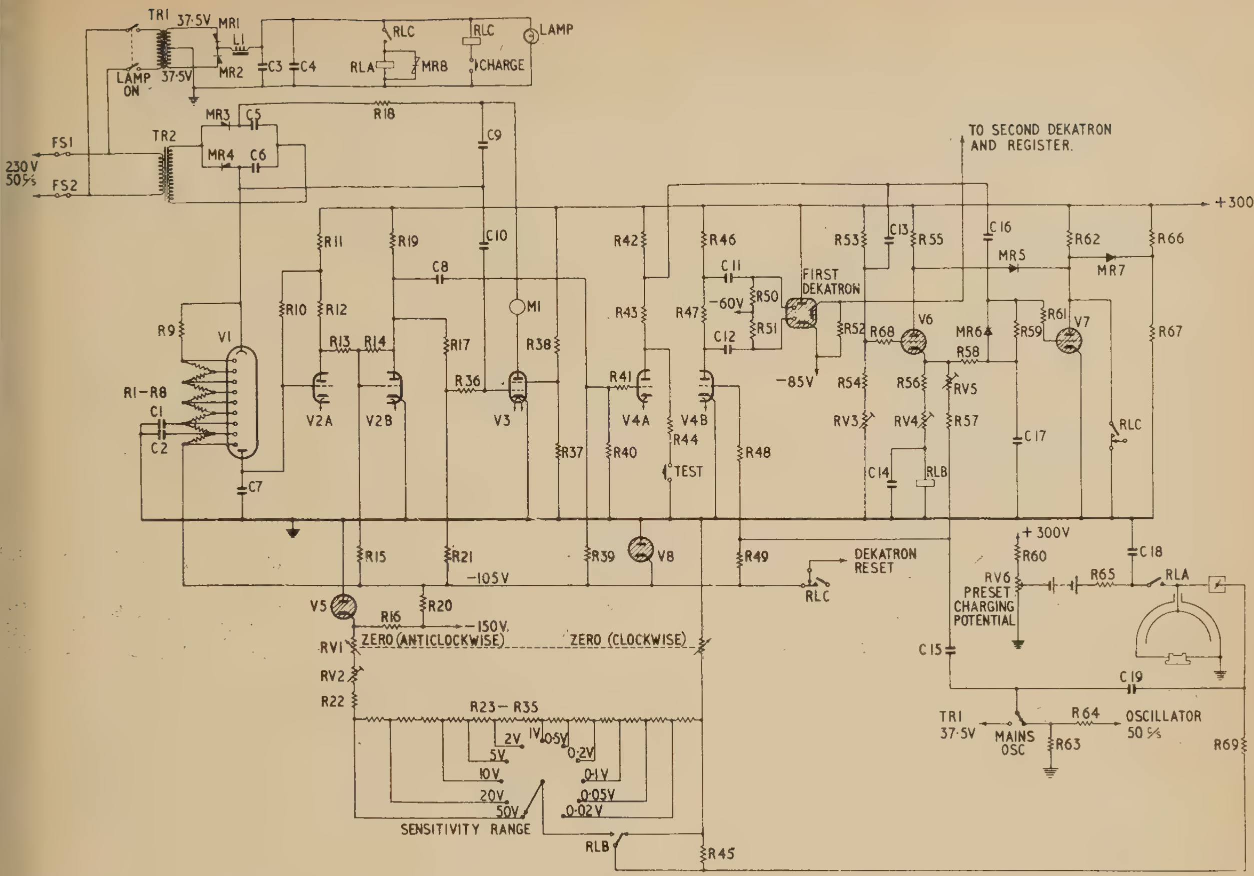
TR1
37·5V
MR1
L1
LAMP ON
37·5V
MR2
C3
C4
RLC
RLA
MR8
RLC
CHARGE
LAMP
MR3
C5
R18
FS1
TR2
MR4
C6
C9
230 V 50 c/s
FS2
TO SECOND DEKATRON AND REGISTER.
+300V
R11
R19
C10
R42
R46
R53
C13
R55
C16
R62
R66
MR5
MR7
C8
C11
FIRST DEKATRON
-60V
R50
R10
R12
M1
R43
R47
R51
V6
R61
V7
R9
V1
R13
R14
R17
R38
C12
R52
R68
MR6
R59
R67
R58
R1–R8
C1
R36
R41
-85V
R54
R56
RVS
V2A
V2B
V3
V4A
V4B
RV3
RV4
R57
C2
R44
C17
RLC
R37
R40
R48
TEST
C14
RLB
C7
R15
R21
R39
V8
R49
DEKATRON RESET
+300V
R60
C18
-105V
RLC
RV6
PRESET CHARGING POTENTIAL
R65
RLA
V5
R20
R16
-150V.
RV1
ZERO (ANTICLOCKWISE)
ZERO (CLOCKWISE)
C15
C19
RV2
R22
R23–R35
TR1 37·5V
MAINS OSC
R64
OSCILLATOR 50 c/s
R63
R69
2V
1V
0·5V
0·2V
5V
10V
0·1V
20V
0·05V
50V
0·02V
SENSITIVITY RANGE
RLB
R45

Fig. 5. Circuit diagram of the photometer timing circuits and automatic control

(For greater accuracy resistors R_{22} to R_{35} are replaced by two standard resistance boxes.)

R_1–R_9 = 330 kΩ
R_{10} = 100 MΩ
R_{11}, R_{12} = 47 kΩ
R_{13} = 680 kΩ
R_{14} = 4·7 MΩ
R_{15} = 330 kΩ
R_{16} = 12 kΩ
R_{17} = 1·2 MΩ
R_{18} = 560 kΩ
R_{19} = 100 kΩ
R_{20} = 5·6 kΩ
R_{21} = 1 MΩ
R_{22} = 20 kΩ
R_{23} = 18 kΩ
R_{24}, R_{25}, R_{26} = 3 kΩ
R_{27} = 1·8 kΩ
R_{28}, R_{29}, R_{30} = 300 Ω
R_{31} = 180 Ω
R_{32} = 60 Ω
R_{33} = 30 Ω
R_{34} = 18 Ω
R_{35} = 12 Ω

R_{36} = 2·7 MΩ
R_{37} = 22 kΩ
R_{38} = 560 kΩ
R_{39}, R_{40}, R_{41} = 1 MΩ
R_{42} = 68 kΩ
R_{43} = 180 kΩ
R_{44} = 680 kΩ
R_{45} = 1 MΩ
R_{46} = 100 kΩ
R_{47} = 68 kΩ
R_{48} = 1 MΩ
R_{49} = 1·5 MΩ
R_{50} = 270 kΩ
R_{51} = 220 kΩ
R_{52} = 150 kΩ
R_{53} = 4·7 MΩ
R_{54} = 680 kΩ
R_{55} = 150 kΩ
R_{56} = 22 kΩ
R_{57} = 680 kΩ
R_{58} = 2·2 MΩ
R_{59} = 1·8 MΩ

R_{60}, R_{61} = 1 MΩ
R_{62} = 1·8 MΩ
R_{63} = 100 kΩ
R_{64} = 470 kΩ
R_{65} = 47 kΩ
R_{66} = 39 kΩ
R_{67} = 50 kΩ
R_{68} = 1 MΩ
R_{69} = 150 kΩ

C_1, C_2 = 0·02 μF
C_3, C_4 = 250 μF
C_5, C_6 = 0·1 μF
C_7 = 680 pF
C_8 = 0·05 μF
C_9 = 0·1 μF
C_{10} = 5000 pF
C_{11} = 0·01 μF
C_{12} = 5000 pF
C_{13} = 3000 pF
C_{14} = 0·25 μF
C_{15} = 2200 pF

C_{16} = 1000 pF
C_{17} = 0·25 μF
C_{18} = 1 μF
C_{19} = 180 pF

$RV1$ = 50 + 50 Ω
$RV2$ = 2500 Ω
$RV3$ = 500 kΩ
$RV4$ = 50 kΩ
$RV5$ = 500 kΩ
$RV6$ = 25 kΩ

$TR1$ = 600 V, 1 mA 6·3 V, 2 A

$TR2$ = 37·5–0–37·5 V, 0·35 A

$L1$ = 0·5 H, 0·5 A

lamp = 20 V, 10 W, A1/131

RLA = 2500 Ω, 1 M Z530018 modified

RLB = 12000 Ω, 1 C, type 1A

RLC = 670 Ω, 2C, 2K

V_1 = PS 2712A
V_2 = CV4024 (12AT7)
V_3 = CV276 (11E2)
V_4 = CV4024 (12AT7)
V_5 = CV4048 (M8098)
V_6, V_7 = CV2257 (UD166C)
V_8 = CV686 (VR105)

Dekatron = CV2271 (GC10B)

FS_1, FS_2 = 3A

M_1 = 500 μA

MR_3, MR_4 = 36 e.h.t. 80
MR_5 = MQ8/3T
MR_6 = MQ3/3T
MR_7 = MQ8/3T
MR_8 = Atmite AA60/1

±1/50 s. Provision is made for using the mains as an lternative 50 c/s time source for less accurate measurements.

When the image of the fibre index overlaps the aperture, n alternating current is amplified by the photomultiplier V_1 nd flows into R_{10}. The resulting alternating potential is mplified by V_2 and applied to the control grid of V_{4A}. Vhen the amplitude of this waveform overcomes the grid ias of V_{4A}, differentiated pulses are applied to the cold athode trigger valve V_6, which fires and immediately raises he grid bias of V_{4B} which amplifies the modulation frequency o drive the first Dekatron. Timing starts from this moment. hortly afterwards, relay *RLB* operates to change the potential cross the electrometer, and the fibre is displaced. Capacitor $_{17}$ charged through R_{58} delays the application of positive ias to another cold cathode trigger valve V_7 until the fibre as been displaced, and this valve then fires when the fibre index overlaps the aperture for the second time. Firing of V_7 extinguishes V_6 and so drops the bias on V_{4B} and stops the timing.

Valve V_2 also controls the grid bias of V_3 which controls the photomultiplier extra high tension in such a way that the mean photomultiplier output current is constant over a wide range of lamp brilliance and photomultiplier gain. The product $C_{10}R_{36}$ delays the action of this circuit and determines the minimum flicker frequency which is detectable.

EXPERIMENTAL RESULTS

In Fig. 6 is shown a plot of measured sweep time *versus* sensitivity range obtained with one radium source. These measurements were taken while there was no significant change in pressure, but are corrected for small temperature changes by assuming that the ion-chamber sensitivity is inversely proportional to absolute temperature. The departure from linearity over the three decades shown increases to 0·18% at the maximum deflexion of 100 V. This effect is probably caused by penetration of field from the earthed frame to the region of the fibre, and could be reduced by better screening.

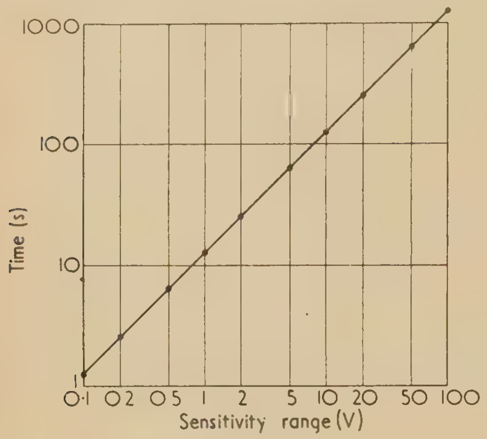

Fig. 6. Readings obtained with one radium source

A good way of checking the instrument over a wide range of activity is to measure one nuclide over several half-lives and see how closely the decay follows an exponential law. Gold 198 was chosen because it has been measured by independent workers with an agreement better than 0·1%,(7) it is chemically stable and its half-life is convenient. A piece of pure gold foil was irradiated in a flux of 10^{12} neutrons/cm^{-2} s^{-1} for 12 s and then measured after 1 day

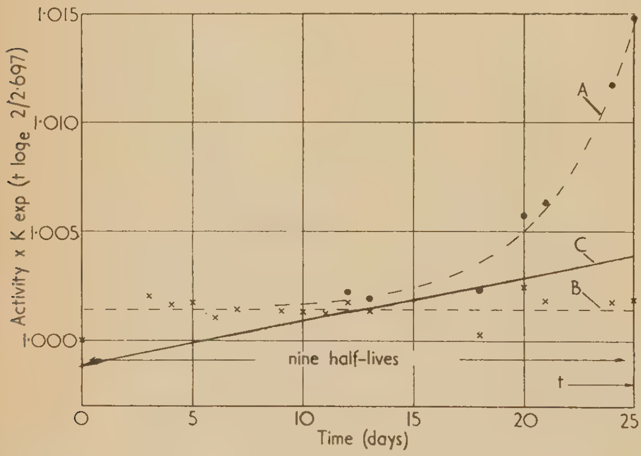

Fig. 7. Measurement of gold 198

A, measured activity with background; *B*, measured activity corrected for background; *C*, predicted slope of line *B* if the measured activity had a half-life equal to 2·699 days.

and at irregular intervals up to 26 days later. The irradiat dose was chosen to be no larger than was necessary to obt an initial ionization current about 100 000 times the b ground of the instrument, and short enough to avoid formation of a significant amount of isotope ^{199}Au.

Sixteen activity measurements were made during ab nine half-lives, and the results are plotted against time Fig. 7. For this graph each measured activity has b multiplied by *K* exp (*t* log$_e$ 2/T), where *t* is the elapsed t to the nearest half-minute and *K* is chosen to make initial activity equal to unity. Line *A* is drawn through measured activity before subtraction of background, an value for *T* equal to 2·697 days was found to make the po lie along a line *B* parallel to the time axis, after correction background. Line *C* is drawn to show the predicted sl of line *B* if the measured activity had a half-life equal 2·699 days.

Some of the points in Fig. 7 are from the average several readings taken consecutively, but no group of measu ments on any one day require correction for duration. readings have been corrected for background 75 mV/h the activity on the last day was about seventy times background. All readings have also been corrected by empirically deduced factor of 0·97 times the change in ra of absolute temperature to atmospheric pressure.

The standard deviation of the sixteen plotted points ±0·0013 days about a mean half-life of 2·697 days, and deviation would be increased to ±0·0032 days if the half were taken as 2·699 days. These figures therefore conf the value 2·697 ± 0·003 days quoted for ^{198}Au by Lock and Thomas.(8)

ACKNOWLEDGEMENTS

The authors are grateful to many colleagues at Harv for help in the construction of the instrument and experime with it; in particular to Mr. F. B. Whiting who designed torsion fibre suspension and electrodes and for his help advice.

REFERENCES

(1) Bartholemew, R. M., Brown, F., Howell, W. Shorey, W. R. J., and Yaffe, L. *Canad. J. Phys.*, p. 714 (1953).

(2) Luger, P. *Rev. Sci. Instrum.*, **26**, p. 948 (1955).

(3) Goodman, P. *J. Sci. Instrum.*, **32**, p. 439 (1955).

(4) Bryant, J., and Michaelis, M. *Radiochemical Cen Report RCC-R/7* (1951).

(5) Sargent, B. W., Yaffe, L., and Gray, A. P. *Canad Phys.*, **31**, p. 235 (1953).

(6) Cooke-Yarborough, E. H., and Whyard, R. E. *Brit Appl. Phys., Suppl.* 3, p. *S*147 (1954).

(7) Bell, R. E., and Yaffe, L. *Canad. J. Phys.*, **32**, p. (1954).

(8) Lockett, E. E., and Thomas, R. H. *Nucleonics*, **11**, p (March 1953).

Decade flux linkage generators

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A description is given of two versions of a self-contained instrument for calibrating flux-meters and ballistic galvanometers. In both, a known constant flux-change is produced by reversing the primary current in a saturated inductor. The desired linkage is then obtained by switching the appropriate number of secondary turns into circuit. Two saturable inductors provide a total flux-linkage change of 11·11 × 10^6 Maxwell-turns in four decades.

SYMBOLS

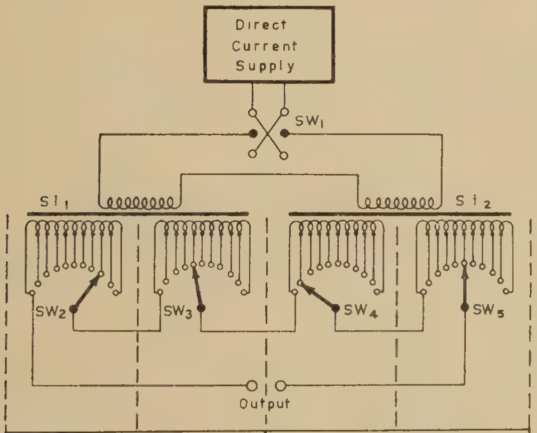
M = mutual inductance.
I = current.
B = flux density in core.
ΔB = small change in B.
H = magnetic field acting on core.
ΔH = small change in H.
$K = \dfrac{\Delta B}{\Delta H}\dfrac{H}{B}$
t = time.
H_c = coercive field.
H_{sat} = saturating field.
ϕ = total flux change.
N = number of primary turns on core.
E = supply e.m.f.
l = iron path length.

INTRODUCTION

lthough instruments are available to provide decade steps f resistance, capacitance and other physical quantities, so ar there has been no single instrument to generate a flux nkage change in this way. Whilst the Hibbert magnetic tandard[(1)] is self-contained, it generates a flux-linkage by the novement of a coil through a gap in the field of a permanent nagnet. It is thus mechanically difficult to provide more han one or two tapped coils on a single instrument, making unsuitable for direct calibration purposes. In the method ccepted by standards authorities[(2,3)] for the calibration of lux-meters and ballistic galvanometers a flux-linkage change f $2MI$ is developed by reversing a current I in the primary f a mutual inductor M. The disadvantages of this method re due, first to the inconvenience of adjusting and measuring he primary current to the required accuracy and secondly to he limitation of the maximum flux-linkage change to about 10^6 Maxwell-turns with a convenient-sized mutual inductor having a low secondary resistance.

The instrument to be described may be considered as a special form of mutual inductor having cores of high permeability material excited just to saturation. In this condition the core fluxes are little affected by changes in primary current and yet at the same time the effective permeability is high enough to ensure that almost the whole flux is carried by the core; the linkage is then governed only by the number of turns in circuit and is practically independent of the position or diameter of a coil around the core. It is thus simple to provide the equal steps required for a decade instrument, by switching an appropriate number of turns into circuit.

The sections and flux densities of the cores shown in Fig. 1 are so adjusted that when the primary current is reversed by SW_1 the fluxes in the saturable inductors SI_1 and SI_2 change by 50 000 and 1000 Maxwells respectively. By means of switches SW_2–SW_5 various numbers of turns linking these fluxes may be connected in series to provide the required total flux-linkage output.



	Flux change in SI_1 = 50 000 Maxwells		Flux change in SI_2 = 1000 Maxwells	
	Winding 1	Winding 2	Winding 3	Winding 4
Turns/step	20	2	10	1
Maxwell-Turns/step	10^6	10^5	10^4	10^3

Fig. 1. Block diagram

CORES OF SATURABLE INDUCTORS

The requirements for a suitable core material for the inductors are similar to those for magnetic amplifier cores with the additional factor that laminations are preferable to a ring core as they facilitate the adjustment of cross-sectional area. Laminations designed for double-lap joints, as used in amplifier cores, are essential to avoid local saturation. Because of its stability and availability in the form of suitable laminations a crystal-oriented 50–50 nickel-iron alloy* was used. This type of material approaches saturation in small fields and the flux is only slightly affected by a further increase in exciting field.

In a ferromagnetic material the saturation induction falls with increasing temperature, becoming zero at the Curie temperature. Below saturation the induction is limited by anisotropy and magnetostriction,[(4)] but since both effects decrease with rise of temperature, various temperature coefficients may be obtained depending on the exciting field. In Fig. 2 are shown curves of induction with temperature for a range of excitation in H.C.R. It is seen that the temperature coefficient drops from the true saturation value in curve (*a*) almost to zero in curve (*h*) at lower excitation. The values in Fig. 2 are replotted in Fig. 3 as *B–H* curves for constant temperatures of 10, 20, 30 and 40° C. From this figure it is seen that there are two possible ways of maintaining a constant flux density over a range of temperature.

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* This material is known commercially as H.C.R. alloy, Permanorn 5000Z, Permalloy PN65, Deltamax, Orthonol, Orthonik or Hipernik V.

Either the exciting field may be varied in accordance with the measured temperature, as shown by the intercepts of the constant flux line PQ with the curves, or the field corresponding to the point T in RS may be used so that the flux change with temperature is negligible. In the former case the temperature coefficient is 0·07% per °C, but the flux is relatively insensitive to current variation: in the latter case zero temperature coefficient is obtained at the expense of a larger current sensitivity. Separate instruments have been built using these alternatives and the design values for the inductors in each version are shown in the table.

The effect of current variations is indicated by the parameter $K = \dfrac{dB}{B}\Big/\dfrac{dH}{H}$, i.e. the proportional change in flux density for a proportionate change in exciting field. T for $K = 1/30$, 3% change in primary current produce change of 0·1% in core flux. It can be shown that, whe logarithmic scale is used for H as in Fig. 3, K is appr mately equal to the gradient of the curve. Lines of const permeability are included in the figure.

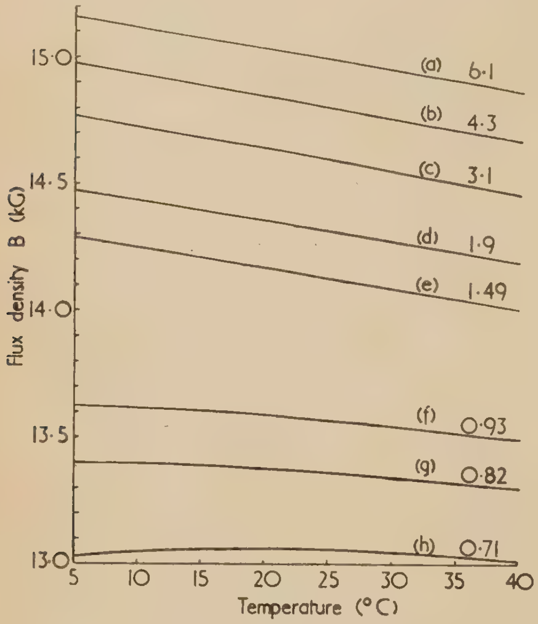


Fig. 2. Flux density B as a function of temperature
Numbers on the graphs are in oersteds.

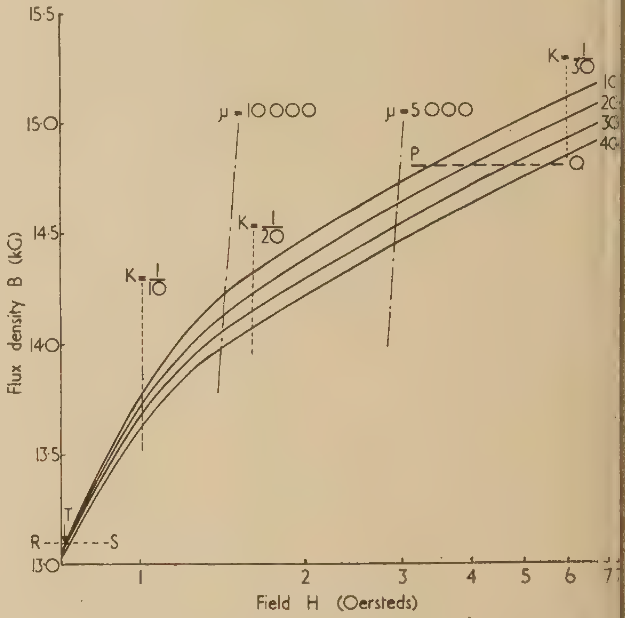


Fig. 3. Flux density B as a function of log H

WINDINGS AND CONSTRUCTION OF INDUCTO

The required ampere-turns to produce a field H is c culated, as for a transformer, i.e. the ampere-turns NI $Hl/0{\cdot}4\pi$, where the path length l for a double-lap core c struction is equal to $6a$, for the lamination form sh in Fig. 4(a).

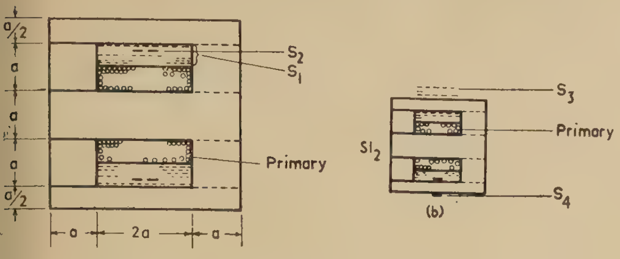
In addition to providing the required field, determined the operating condition of the cores, it is necessary to des

Table of design values for inductors

	Low current coefficient SI_1	SI_2	*Low temperature coefficient* SI_1	SI_2
Core flux density (kG)	14·8		13·1	
Core section (cm^2)	1·69	0·0338	1·91	0·0382
Lamination type number, Telcon	226	224	226	224
Dimension a (Fig. 4) (in.)	0·5	0·25	0·5	0·25
Lamination thickness (in.)	0·004	0·004	0·004	0·004
Number of laminations	131	10½*	148	12*
Core path length $6a$ (Fig. 4) (cm)	7·62	3·81	7·62	3·81
Core induction temperature coefficient (% per °C)	0·07		0	
Core current coefficient $\dfrac{dB}{dI}\cdot\dfrac{I}{B}$	0·038		0·12	
Exciting field (Oersteds)	3·5–5·5		0·73	
Primary current (A)	0·21–0·33		0·009	
Flux reversal time (s)	0·046–0·044		0·015	
Primary turns	100	50	500	250
Wire gauge (enamelled s.w.g.)	22	24	32	36

* See section on adjustment of instrument.

e primary circuit so that the core flux reverses sufficiently pidly. This time is critical when testing a ballistic galvanoter, but a reversal time less than 0·1 s is usually adequate.(5)



(a)

Fig. 4. Arrangement of inductor windings and lamination form

r a material having ideal magnetization properties, the ne t for a flux change ϕ is

$$t = \frac{N\phi}{E} \times 10^{-8}\ \mathrm{s}$$

ere N is the number of primary turns and E is the supply ltage. For a material having a square hysteresis loop of ercivity H_c and saturating field H_{sat},

$$t = \frac{N\phi}{E} \times \frac{H_{sat}}{(H_{sat} - H_c)} \times 10^{-8}\ \mathrm{s}$$

The self-heating effect for the windings specified in the ble was measured. It was found that the highest temrature rise in any winding (i.e. 0·33 A in SI_2) was ½° C ich has a negligible effect on the flux density.

By using cores of high permeability as described previously, almost equal increments of flux-linkage are obtained in each section of a secondary winding. For greater accuracy, each section employing one conductor is made to link the same leakage flux by winding a complete secondary with a conductor assembly consisting of 10 strands. For convenience of winding, the strands (of 28 B and S enamelled copper wire), are laid adjacently on to an adhesive polythene tape. For the greatest consistency between the first two decades, secondaries S_1 and S_2 are interleaved to link the same leakage flux.

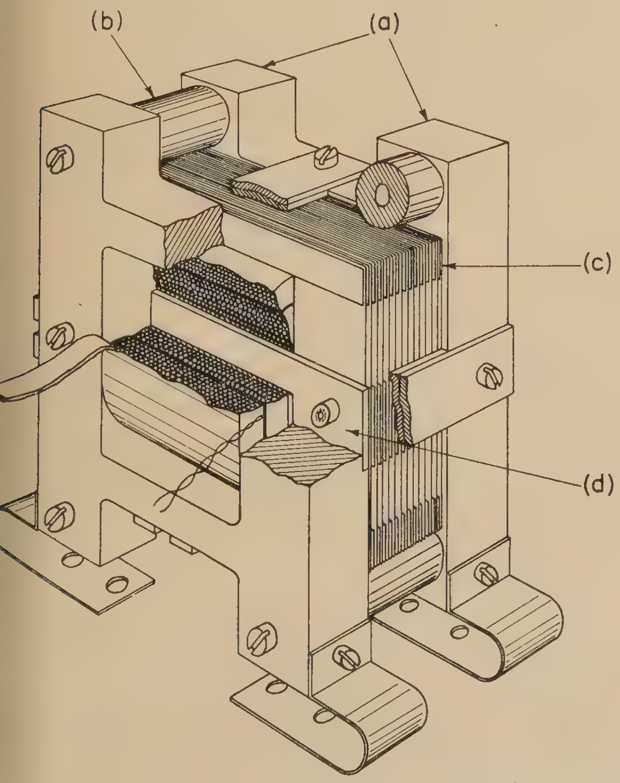


Fig. 5. Cut-away view of inductor assembly SI_1

The small cross-section of SI_2 would require an inconveniently small number of laminations if the secondaries were wound on the centre limb. By using the narrow outer limbs as in Fig. 4(*b*) a greater stack height is employed and the secondaries link less leakage flux, being closer to the core. As described subsequently this arrangement also facilitates adjustment of the core cross-section.

The maximum stability of core flux is obtained when the cores are supported on all sides and constrained as little as possible. This is accomplished by the assembly shown in Fig. 5 for SI_1, a similar scheme being used for SI_2. The core laminations (*c*) are supported by heavy brass plates (*a*) whose separation is rigidly governed by the length of the spacers (*b*), the windings being supported by brass strips (*d*). By experiment the core was found to have optimum permeability and reproducibility when the stacking factor was about 80%, which allows the laminations to be almost loose.

POWER SUPPLIES

(*a*) The version of the instrument employing non-zero temperature coefficient makes use of a battery supply shown in Fig. 6(*a*). The low accuracy to which the current need be set (±2% for 0·1% instrument accuracy) allows the use of a relatively low priced instrument to indicate the inductor primary current. The appropriate current is determined by the temperature, which is measured by an angle-type thermometer having its bulb adjacent to the inductors, and is

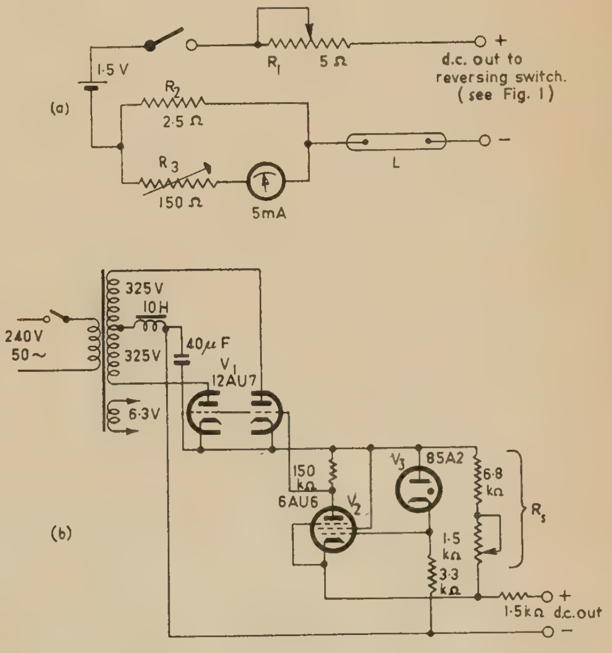


Fig. 6. Circuits of power supplies: (*a*) battery power supply; (*b*) mains operated power supply

adjusted by a multi-turn potentiometer R_1. R_3 is preset to enable a convenient range of current to be indicated by the meter. Where greater reproducibility is required the removable link L allows substitution by an accurate meter or shunt.

(*b*) The zero temperature coefficient version requires only a single value of current but this must be stable to better than 1%. A mains-driven power supply was found necessary and a suitable circuit is shown in Fig. 6(*b*). The d.c. output current develops across R_s a potential which is compared with that across a reference tube V_3. In this circuit a mains variation of ±10% produces a change in output current of less than ±0·1%.

ADJUSTMENT OF INSTRUMENT

Correct adjustment of the instrument was obtained by means of a precision mutual inductor, the primary current of which was measured with a shunt and potentiometer. A null method was used with a flux-meter as indicator.

The section of SI_1 was first adjusted to the nearest lamination; the final adjustment was then made by setting the primary current to obtain the correct linkage. With this primary current, the cross-sectional areas of the outer limbs of SI_2 were reduced to the required value for S_3 and S_4 by trimming the outside edge of each limb of one of the laminations. Whilst this induces some strain in one lamination it was found that the use of a sharp guillotine produced negligible effect on the whole core.

CONCLUSIONS

The range and accuracy is entirely adequate for test flux-meters and ballistic galvanometers and is more c venient than existing methods. The stability of the instrum has been confirmed by periodic checking.

For use over a wide range of temperatures without co pensation an alloy less affected by temperature would desirable for the inductor cores. From published wor on experimental alloys of the Perminvar type (Fe–Ni–Co) would appear that material of this nature might be suita particularly after magnetic annealing.

ACKNOWLEDGEMENT

The author is indebted to Mr. Clothier of this Division most helpful advice and the supply of the ten-strand w which he had developed for a precision decade transform

REFERENCES

(1) Glazebrook, R. *Dictionary of Applied Physics*, Vol p. 458 (London: Macmillan and Co. Ltd., 1922).
(2) Amer. Soc. for Testing Materials (Ferrous Metals) Sta A34–55.
(3) Brit. Stand. 2451 (1954).
(4) Bozorth, R. M. *Ferromagnetism*, p. 713 (New Yo Van Nostrand Co. Inc., 1951).
(5) Wenner, F. *Phys. Rev.*, **25**, p. 139 (1907).
(6) Bozorth, R. M. Brit. Stand. 2451, pp. 160–80 (1954

A recording double-beam attachment for the Unicam type SP500 spectrophotometer

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[*Paper received* 15 *November*, 1957]

A review is made of published accounts of double-beam attachments for spectrophotometers, for use in the visible and ultra-violet region. A simple alternate-path unit, incorporating a single type 1.P.28 photomultiplier detector, is described. A ratio-recording amplifying system is employed, and the spectrometer slit width is monitored by a servomechanism to give a constant "reference" output from the amplifier. A compact wavelength drive is incorporated.

A number of recording double-beam attachments for visible and ultra-violet spectrophotometers have been described$^{(1-8)}$ in recent years. A ratio-recording system is normally employed rather than one involving mechanical attenuation of the "reference" radiation beam. Ratio-recording is variously achieved by using two detectors,$^{(1, 7)}$ by interrupting the two beams at different frequencies$^{(3)}$ and by interrupting the two beams at the same frequency but in different phase.$^{(2, 4-6, 8)}$

Usually, a constant "reference" output is obtained either by monitoring the slit width$^{(1-4, 7)}$ or by monitoring the photomultiplier voltage$^{(5, 6, 8)}$ and hence the signal amplification. In two instances$^{(5, 8)}$ the photomultiplier voltage is monitored by the "reference" output to keep the latter at a very constant level, and only the "sample" output is recorded.

In the equipment described below a single photomultiplier detector is employed. An alternate-path optical system involving a rotating sector causes two radiation beams, 180° out of phase, to fall on the same area of the detector cathode. After amplification the two electrical signals are separa and rectified by a mechanical switch on the sector shaft, the ratio of the two outputs is measured on a record potentiometer. The "reference" output is maintained a constant level by a slit servomechanism. The amplify and recording equipment is designed to be interchange between an infra-red spectrometer$^{(9)}$ and the present spec meter attachment.

GENERAL

The main advantages of a recording instrument over employing manual measurement lie in the rapid recordin complex data and in the ready detection of weak bands shoulders due to minor components. Moreover, since it hitherto been normal practice to use a photocell detecto instruments employing manual measurement, the pho multiplier detector normally used in recording equipm results in a considerably higher sensitivity. Under rou rking conditions a reduction in spectral bandwidth of as ich as five times may be made.

Automatic recording often entails a certain loss of pre- ion in quantitative measurements. The alternate-path it described has therefore been made readily interchange- le with the existing sample and photocell compartment, to rmit rapid reversion to manual operation.

DESCRIPTION OF APPARATUS

Alternate-path optics. Details of the double-beam optical stem are shown diagrammatically in Fig. 1. The unit is ntained in a box of $\frac{3}{8}$ in. ebonite, flanged at the edges to oid entry of light.

The sector *SR* has a diameter of $7\frac{1}{2}$ in. and is rotated with e rectifier switch *RS* at about 4 c/s by a Nylon cord drive.(9) e rotating mirror M_2 can be adjusted in the plane of the ctor to minimize movement of the slit image on the detector ring rotation. It is essential that this adjustment should made carefully, since otherwise the amplifier outputs will ve poor long-term stability. The aluminized spherical irrors M_1 form diffuse slit images of width 2–3 mm at the otomultiplier cathode *P*. Shutters *SH* can be brought to either beam to check the zero output level.

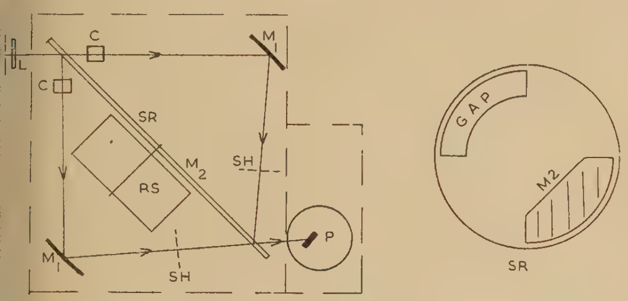


Fig. 1. Optical layout

S, exit slit of SP500 with quartz lens *L*; *C*, 1 cm cell positions; M_1, spherical concave mirrors, 6 in. focal length; M_2, plane mirror (both sides) on sector *SR*; *RS*, rectifier switch; *P*, photomultiplier detector; *SH*, shutters

Although cells of up to 5 cm in length could be accom- odated, provision has been made only for 1 cm cells. hese are introduced *via* $\frac{3}{4}$ in. holes in the lid into vertical ells which locate the cell holder in position in the beam *C*. Any room light reaching the photomultiplier during e introduction or removal of cells is interrupted by the ctor, so that the presence of excessive amounts of such ght is indicated immediately on the amplifier output meters. o reduce light from this source, the holes in the lid are ght-baffled and are covered during operation.

The sensitivity of the 1.P.28 cathode surface is known to e non-uniform(3, 5, 6) and has been shown(10) to fall by bout 25% on moving 1 mm sideways from the central nsitive region. The same investigation showed that for ny particular tube the spectral sensitivity of different parts f the cathode had fairly uniform wavelength distribution aracteristics. This does not apply to two different tubes(1, 7) owever, hence the use of a single detector in the present work.

Owing to the variable sensitivity of the detector cathode, is desirable to make the two optical paths of equal length order to ensure that both beams have identical cross- ctions at the cathode. If this condition is not fulfilled, ariation in slit width will produce a second-order effect hich will vary the ratio of the outputs. At very narrow slit widths, small irregularities in the slit jaws cause significant vertical asymmetry in the slit image at the detector, and matching of the two beams is effected by an external screw adjustment which tilts one of the M_1 mirror brackets forward. This adjustment is correlated empirically with the flatness of the 100% transmission line near 600 mμ, where a large variation in slit width occurs. It is the most critical of several adjustments, the combined object of which is to ensure uniform(10) and identical distribution of radiation in both beams, and to bring the beams from the same direction through the same section of the detector envelope on to the same central area of the cathode.

Electronics. The radiation sources supplied by Unicam Ltd., comprising a hydrogen lamp with stabilized power pack and an accumulator-fed tungsten lamp, are used with the present equipment. The photomultiplier power supply consists of a conventional series-stabilized power pack, the output of which can be varied to give a maximum of 900 V across a chain of 100 kΩ resistors. These are connected to the 1.P.28 dynodes and a 5 MΩ anode load is used.

The electronic amplifier(9) previously described for an infra-red spectrometer is employed with the present ultra-violet spectrometer attachment. The pre-amplifier is omitted in the present use, and the main amplifier is operated at retarded voltage gain values of the order of one hundred.

The following modifications to the original circuit(9) are important. The h.t. power supply has been redesigned, so that one series-stabilized pack (0 to -115 V) is run from another series-stabilized pack ($+230$ to -115 V), both packs using the same neon tube as a reference voltage.

The output valves $V_{8,9}$ are now operated from the $+230$ V line, with 50 kΩ resistors connected to the screen grids. The capacitors to earth from the cathodes of $V_{8,9}$ have been reduced from 1000 to 500 μF, while the resistors attached to the control grids have been reduced from 200 to 10 kΩ. This reduces the fastest response time to 0·9 s (90% response) but retains adequate smoothing.

The cathode follower V_3 is now decoupled from the $+150$ V line, and an additional 25 kΩ resistor in the anode permits the use of the anode signal to give the required phase relationship at the rectifier switch. The arrangement involves an *RC* couple from the photomultiplier anode to the gain control RV_1, and an *RC* couple from the anode of V_3 to a 100 kΩ resistor attached to C_7, which connects with the V_4 stage.

The capacitor between the anodes of V_4 and V_5 has been increased to 0·05 μF to limit the high-frequency response of the amplifier. This permits removal of the 100 c/s rejection filter which causes considerable distortion of the waveform in the situation shown. Only the lower of the two gain settings for the section V_{4-6} is now used.

The rectifier switch layout is similar to that originally described,(9) but lightly annealed beryllium–copper strips (0·01 in.) with silver stud contacts are used in place of relay contacts. All strips are sprung slightly against shorter backing strips (0·04 in.) which result in more consistent operation by preventing chatter of the contacts. The contacts are adjusted to make over 15–20° of rotation. This switch mechanism has given no trouble at all on the infra-red spectrometer over a period of five years.

The slit servomechanism is identical with that originally described,(9) the velodyne generator being used under maximum feedback conditions. The velodyne motor is linked to the SP500 slit drive by a 50 : 1 worm reduction gear. A microswitch on the "reference" beam shutter switches on the velodyne motor when the shutter is fully open.

An Electronic Recorder (by Cambridge Instrument Co. Ltd.) (1·2 s to 90% response) is used. This is set to be slightly underdamped and has a very sensitive and consistent performance.

Wavelength drive. The wavelength drive consists of a 40 rev/h synchronous motor (type S7, by Sangamo Weston Ltd.) mounted on two pillars. The driving shaft is linked by a pawl-and-ratchet clutch to a cam and ½ in. gear on the same axis. The cam engages a microswitch which makes contact on the steep part of the cam. This action discharges a capacitor through a relay, which supplies a wavelength calibration voltage pulse to the recorder *via* a 100 μF electrolytic capacitor. The ½ in. gear fixed to the cam meshes permanently with a 2½ in. gear on the SP500 wavelength shaft. A further ½ in. gear fixed to the latter meshes with a 2½ in. gear on which a knurled knob may be set in any of seven wavelength positions. This knob actuates a microswitch, shutting off the wavelength and chart drives at one of the seven positions. Brass reduction gears (48 d.p., machine cut) are used throughout, and all components are mounted on two plates, each of which is fixed to the front panel of the SP500 by two screws only.

The range 200–1000 mμ is normally scanned in 25 min, but for occasional measurements on fine structure or accurate optical densities of narrow bands, the 40 rev/h motor can be rapidly replaced by a 10 rev/h motor of similar design. The wavelength scale has the same characteristic as that of the unmodified SP500 and so is not linear in wavelength.

PERFORMANCE

The resolution of the equipment in the ultra-violet region is illustrated by Fig. 2, which shows part of the spectrum of benzene vapour (1 cm cell). This was obtained with the 2 s response setting at the slower scanning speed (see above). The spectral bandwidths are equivalent to those quoted for the Cary spectrophotometer on A.P.I. Project 44 Ultra-violet Spectrogram No. 639 (benzene vapour). Performance in the visible region is illustrated by Fig. 3, which shows the spectrum of a mixture of rare earth chlorides (dysprosium 60%, holmium 10%, erbium 16%, 10% aqueous solution, 1 cm cell), obtained with the 1 s response setting at the faster scanning speed.

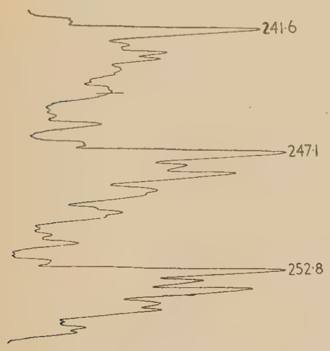


Fig. 2. Benzene vapour (1 cm cell)

(Wavelengths are in mμ.)

In both the ultra-violet and visible regions, the overall variation of the 100% transmission line can usually be kept below 4%. A glass filter (1% transmission at 520 mμ) improves the base-line flatness and consistency considerably in the visible region, by smoothing out the sensitivity peak near 600 mμ. However, this procedure restricts the working range to 370–700 mμ. Since the shape of the base-line is somewhat dependent on the slit programme where no filter is used, care must be exercised in the case of quantitative differential analysis.

With no filter present, the level of scattered radiat increases abruptly beyond about 750 mμ, reaching ab 50% at 900 mμ. Qualitative and semi-quantitative work still possible in this region, as seen from Fig. 3.

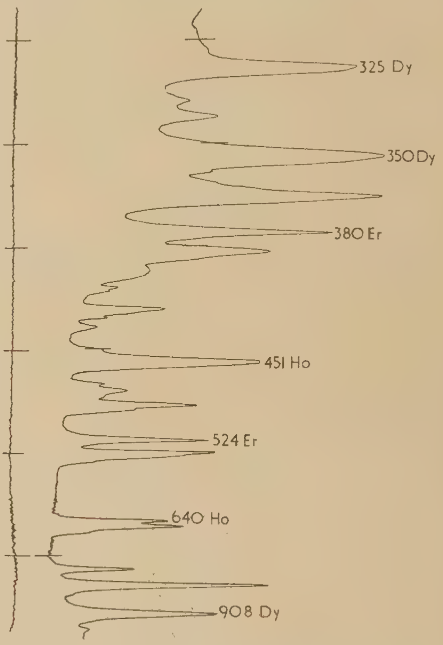


Fig. 3. Mixture of rare earth chlorides

For fuller details, see text. (Wavelengths are in mμ.) Th 100% transmission base-line is also shown.

Random voltage fluctuations at 100% transmission due almost entirely to Shottky noise in the detector, a dark current variations are negligibly small in the prese application. Since the Shottky noise level is a square functi of the radiation energy level at the detector, the noise le becomes much smaller at low transmittance.

ACKNOWLEDGEMENTS

Thanks are due to Mr. H. Saville for the construction the attachments described above. The work described form part of the research programme of the Chemical Resear Laboratory, and this paper is published by permission of Director.

REFERENCES

(1) Coor, T., and Smith, D. C. *Rev. Sci. Instrum.*, 1 p. 173 (1947).

(2) Kaye, W., and Devaney, R. G. *J. Opt. Soc. Ame* **42**, p. 567 (1952).

(3) Etzel, H. W. *J. Opt. Soc. Amer.*, **43**, p. 87 (1953).

(4) King, W. H. *J. Opt. Soc. Amer.*, **43**, p. 866 (1953).

(5) Nelson, R. C., and Jenkinson, R. *J. Opt. Soc. Ame* **43**, p. 1181 (1953).

(6) Yang, C.-C., and Legallais, V. *Rev. Sci. Instru* **25**, p. 801 (1954).

(7) Royer, G. L., Lawrence, H. C., Kodama, S. P., a Warren, C. W. *Analyt. Chem.*, **27**, p. 501 (1955).

(8) Hariharan, P., and Bhalla, M. S. *J. Opt. Soc. Ame* **47**, p. 378 (1957).

(9) Hales, J. L. *J. Sci. Instrum.*, **30**, p. 52 (1953).

(10) Keohane, K. W., and Metcalf, W. K. *J. Sci. Instru* **32**, p. 259 (1955).

Laboratory and workshop notes

Magnetic measurements with the bridged-T network

By J. K. Choudhury, M.Sc., M.Sc.Tech., A.M.I.E.E., and P. C. Sen, B.E.E., Jadavpur University, Calcutta, India

[*Note first received* 21 *June, and in final form* 12 *September*, 1957]

Iagnetic loss is measured by the electrodynamic watt-ıeter(1) at power frequency and at low audio-frequencies. he electrostatic wattmeter(2) has been used with great dvantage over the entire audio-frequency range with the issipation in the core ranging from a few micro-watts to ·veral watts. Various alternating current bridges,(1,3) g. Owen's bridge, Hay's bridge, Maxwell's bridge and the ·ries resonance bridge, have been employed for the measure-ıent of magnetic loss and a.c. permeability at power, audio-ıd radio-frequencies. The present authors have used the ridged-T network(4) for the measurement of these quantities nder various conditions of excitation, at frequencies between) c/s and 50 kc/s, with sinusoidal flux variation in the core. his network offers some definite advantages over the onventional bridge circuits.

Considering the *C–R–C* T-network of Fig. 1(*a*), its transfer npedance (i.e. the ratio "input voltage/output current") ın be shown to be:

$$Z_T = (2/jwC) - (1/Rw^2C^2) \qquad (1)$$

hich is the impedance of the network represented by ig. 1(*b*). A null at the output can be obtained if the '–*R*–*C* T-network of Fig. 1(*a*) is "bridged" by connecting coil of impedance Z_x across the two capacitors to form the ridged-T network of Fig. 1(*c*), such that $Z_x = -Z_T$. Thus ıe balance conditions of the bridged-T network will be iven by:

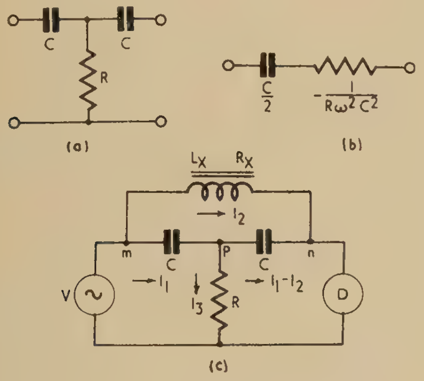


Fig. 1. Networks and circuit

(*a*) *C–R–C* T-network. (*b*) Network representing the "transfer impedance" of the T-network of (*a*). (*c*) Bridged-T null circuit

$$\left.\begin{aligned} L_x &= 2/w^2C \quad \text{and} \\ R_x &= 1/Rw^2C^2 \end{aligned}\right\} \qquad (2)$$

he circuit of Fig. 1(*c*) has been used by the present authors or magnetic measurements; the coil used as the bridge arm ontains the magnetic core. It is important to note that at alance, the total input supply voltage appears across the est-coil L_xR_x—a very useful condition which is not possible to achieve in any other conventional bridge circuit used for magnetic measurements. This keeps the flux waveform as the integral of the supply voltage waveform, since the resistance in the magnetizing circuit is the small resistance of the magnetizing coil only.

The vector diagram of the currents and voltages of the branches of the bridged-T circuit of Fig. 1(*c*) at balance has been developed by the authors and is shown in Fig. 2. In this figure, the current I_2 flowing through the bridge arm L_xR_x lags the input voltage V by an angle θ which is less than 90°. For zero transmission through the detector, the current vector I_2 must be equal and opposite to the vector of current $(I_1 - I_3)$, which thus lags the vector of I_2 by 180°. Also, the vector voltage I_3R is equal to the vector voltage $-j(I_1 - I_3)/wC$, at balance. But, since the vector $-j(I_1 - I_3)/wC$ lags the current $(I_1 - I_3)$ by 90°, it must be in phase with the vector jwI_2L_x. Hence the voltage I_3R and consequently the current I_3 will be in phase with the vector voltage jwI_2L_x. The vector current I_1 is found by the addition of the vectors of currents I_3 and $(I_1 - I_3)$.

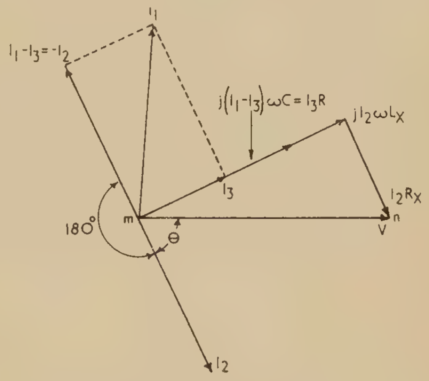


Fig. 2. Vector diagram of the branch currents and voltages of the bridged-T network of Fig. 1(*c*) at balance

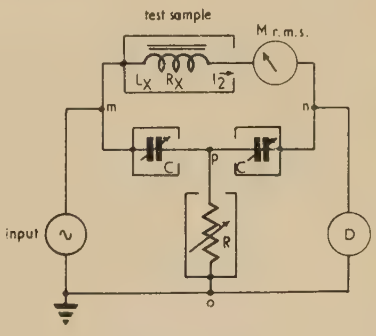


Fig. 3. Screened bridged-T network used for magnetic measurements

The actual circuit of the bridged-T network with the components screened, as used by the authors, is shown in Fig. 3; L_x and R_x represent the effective inductance and loss component respectively of the iron-cored coil. The term R_x includes the magnetic loss component and the winding resistance of the coil. In the circuit of Fig. 3, one point of the supply source as well as that of the detector has been earthed, thereby giving this circuit definite advantages over other bridges in respect of errors due to earth capacity effects. With the screened components connected as in Fig. 3, the earth capacities of the test sample L_xR_x and of the capacitor on the supply side merely shunt the supply source. Also, the earth capacity of the capacitor on the detector side shunts the detector only and does not affect the balance conditions. The earth capacity of the resistance R which forms the shunt arm of the C–R–C T-network need not be taken into account, since its screen is at earth potential. The only earth capacity which may affect the balance conditions is that of the point p, which is the junction point of the three components of the C–R–C T-network. This earth capacity is, however, too small to be taken into account up to very high radio-frequencies.

If R_w represents the winding resistance of the coil on the test core, the magnetic loss in the core can be found from the expression $I_2^2(R_x - R_w)$. Also, with N turns of winding on the core having a mean length of magnetic path of l cm and a cross-sectional area of A cm^2, the complex a.c. permeability of the core material can be found, by measuring the effective inductance L_x, with the help of the formula:

$$\mu_{a.c.} = \frac{L_x l \times 10^9}{4 . \pi N^2 A} \tag{3}$$

A modified circuit of the bridged-T network which is shown in Fig. 4, has been developed and used by the present authors for the measurement of incremental permeability and core-loss with superposed direct and alternating induction in the core. The high value capacitor C_B blocks the direct current path through the a.c. supply source. The permanent magnet moving coil meter M$_{d.c.}$ indicates the magnitude of the direct current passing through the core winding. The r.m.s. value of the alternating current passing through this winding can be found from the difference of the readings of the meters $M_{r.m.s.}$ and M$_{d.c.}$.

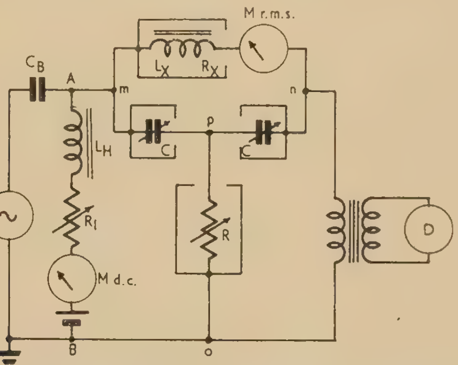


Fig. 4. Modified bridged-T network for magnetic measurements under incremental conditions

REFERENCES

(1) Astbury, N. F. *J. Instn Elect. Engrs*, **95** (II), p. 607 (1948).

(2) Choudhury, J. K., and Glynne, A. *Proc. Instn Elect. Engrs*, **98** (II), p. 539 (1951).

(3) Richards, C. E., Buckley, S. E., Bardell, P. R., and Lynch, A. C. *Proc. Instn Elect. Engrs*, **97** (II), p. 236 (1950).

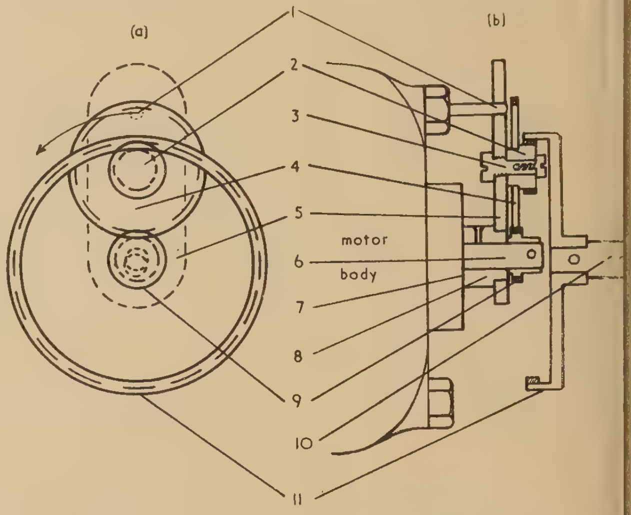
(4) Tuttle, W. N. *Proc. Inst. Radio Engrs*, **28**, p. 23 (1940).

An adjustable geared coupling for misalined shafts

By A. L. Sims, Physiology Institute, University College, Cardiff

[*Note received* 29 *July*, 1957]

A successful attempt has been made to design an adjustab positively driven, and geared coupling, to overcome a co stantly recurring difficulty, viz. a geared down speed reducti between two shafts where their ends are close togeth parallel with each other, but misalined. Reference to pa (*a*) and (*b*) in the figure will show two shafts in this conditio (6) is the driving shaft and (10) is the driven shaft. Pinn



Two views of coupling

to the end of the driving shaft (6) is a toothed wheel (9) a filling the space left on the shaft between it and the face of the driving motor body a free running bearing (8) is fitt To a shoulder on this bearing (8) a flat metal lever (5) soldered, this lever (5) can describe an arc in the directi of the arrow shown on (*a*). Projecting from the lever (5) a steel spindle (3) on which rotates the toothed wheels and (4); they turn together on the spindle (3) because th are soldered to each other.

The correct distance apart of wheels (9) and (4) is obtain by fixing the spindle (3) to the lever (5) at the requisite distan for them to mesh properly, but the correct meshing of t toothed wheel (2) with the internal toothed wheel (11) pinn to the driven shaft (10), is obtained by moving the lever around the driving shaft (6). Owing to shafts (6) and (1 not being in line with each other the movement of lever around the driving shaft (6) brings the teeth of both whe closer together or *vice versa*. When the correct setting obtained by this means both wheels are permanently held this position by locking the lever (5) to the motor body means of the pin (1).

Apparatus for measurement of thermal E.M.F. in semi-i conductors

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[*Note received* 16 *October*, 1957]

Since semi-conductor specimens are often available only small prisms or thin laminae, thermoelectric measureme offer problems in thermometry not encountered when t terial is in the form of a wire. In order to make an curate measurement of the temperature of their specimens anavi and Kashtanova(1) have screwed thermocouples on the specimen surface and then coated them with a water-ss and asbestos mixture. Hutson(2) has used subsidiary aters on his thermocouple leads to obviate a temperature dient along them. An apparatus which has been in use some months in this laboratory offers a very simple way achieving a similar end.

A copper cylinder *A* is bored out along its axis to within nm of the end wall. A thermo-junction *B* is held against inner face of this cylinder. A constantan heater *C* is ound on a recess in this cylinder, a sheet of asbestos paper ing interposed between cylinder and heater and the recess led in with Fortafix (by Fortafix Ltd.). This is capable of oducing a temperature of above 200° C. The reference nctions of the thermocouple are sealed into glycerine filled ass tubes which are immersed in a rectangular copper nk *D* filled with ice/water. The wall thickness of the tank 1 mm. The specimen *E* is held between the end wall of e heated cylinder and the tank, leads being taken from the o latter to measure the thermal e.m.f. developed across the ecimen.

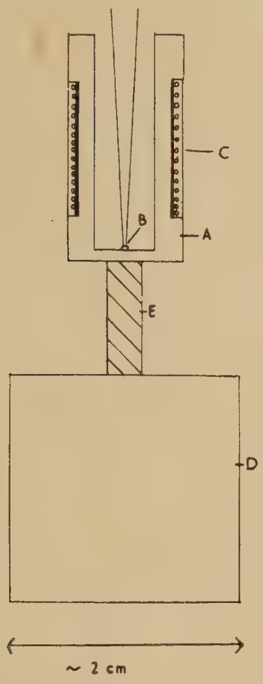


Diagram of apparatus

A computation based on the measured heat flux through a $\times 2 \times 10$ mm specimen of thermal conductivity 0·015 cm cm^2 s °C suggests that the temperature gradient between e thermocouple junction and the specimen face in the ated cylinder does not exceed 0·05° C. Similarly for the mperature gradient across the wall of the ice/water tank. ese could be reduced even further by a reduction in pper wall thickness.

The error due to the finite volume of the thermojunction is viated by its location in what is effectively an isothermal closure.

REFERENCES

SKANAVI, G. I., and KASHTANOVA, A. M. *Soviet Phys. Tech. Phys.*, **1**, p. 882 (1957).

HUTSON, A. R. Bell Telephone Labs. Private communication to F. N. Kröger.

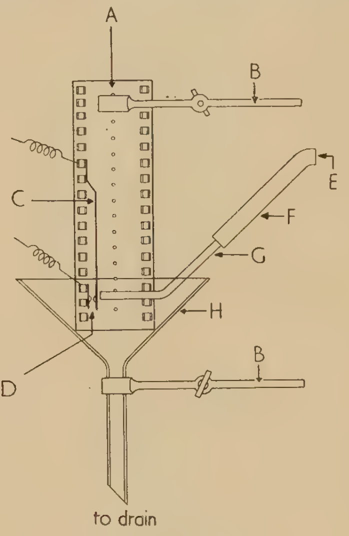
A sensitive and quickly made water flow switch

By G. W. GREEN, Royal Radar Establishment, Great Malvern, Worcestershire

[*Note received* 29 *October*, 1957]

A device was required which would switch off the power supply of an instrument if the cooling water failed. The flow was only 1 l./min and, as no water flow switch of this sensitivity was readily available, the one to be described was devised and made in less than an hour.

The outlet water from the instrument passes through the copper tube (see figure), and impinges as a jet upon the free end of the flexible brass strip. If the flow is adequate the strip is deflected so that the contacts close. The water is thereafter collected by the glass funnel and flows to the drain. The sensitivity is adjusted by bending the brass strip so that it bears with more or less pressure against the end of the copper tube. It is possible to set the sensitivity so that the contacts may be closed by blowing gently down the tube. The components were soft soldered to convenient tags of a tag panel of the type used in electronic apparatus. This was stiffened by bolting a piece of Meccano metal angle along the back. The copper tube was reduced to approximately $\frac{1}{16}$ in. diameter at the end. The contacts were salvaged from an old relay.



Water flow switch

A, tag panel 8 × 2½ in.; *B*, *B*, clamps; *C*, springy brass strip 5 × ½ in. cut from 0·015 in. Shimstock; *D*, contacts approximately $\frac{1}{16}$ in. apart; *E*, water from instruments; *F*, rubber tube; *G*, copper tube; *H*, glass funnel 6 in. diameter.

It was necessary for the controlled instrument to remain off if the water supply failed but came on again, so the contacts were used to control a suitable relay circuit run from a low voltage; it would be undesirable for the exposed metal parts to be connected directly to the mains supply.

A device for the preliminary cutting of single-crystal metallic rods to a desired orientation

By T. B. VAUGHAN, M.Sc., A.I.M., Department of Industrial Metallurgy, University of Birmingham

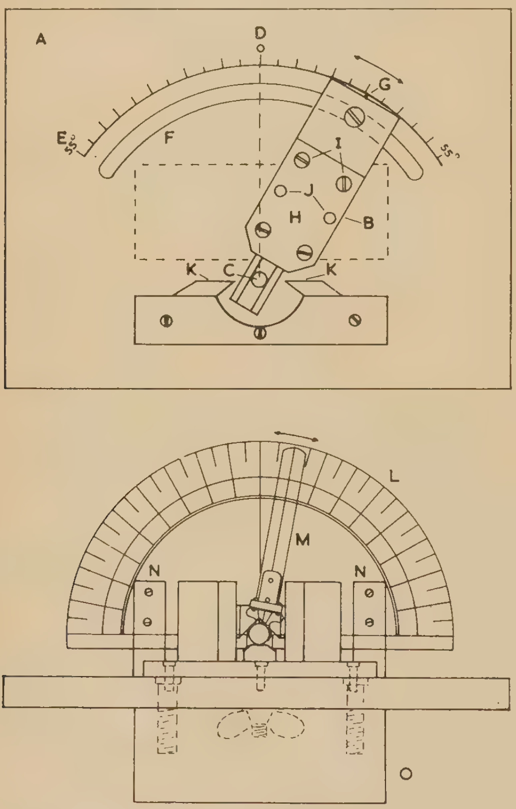
[*Note received* 2 *October*, 1957]

A metal single crystal having a metallographically prepared surface of known orientation is frequently required when the variation of some physical property with orientation is being studied. Methods of producing such surfaces have been described(1, 2) in which the specimen is held in a special jig, which enables it to be transferred from an X-ray diffractometer to a surface grinder. The orientation is determined by the Bragg reflexion method, and by repeated application of the technique an accuracy of five to ten minutes of arc is claimed.

In the course of a study of electrodeposition, it was required to cut sections of $\frac{3}{8}$ in. diameter single-crystal copper rod to exact orientation. The necessary requirements for a cutting apparatus appeared to be as follows:

(1) provision of sufficient degrees of freedom to allow any plane (*hkl*) to be cut from the crystal;
(2) the specimen should be supported in such a way that distortion is avoided during cutting; (3) the cut surface should be as plane as possible and require the minimum of further preparation;
(4) the time required to produce a strain free specimen should be as short as possible.

Of the methods available to meet requirements (1) to (4) machine cutting and acid sawing have both been employed.(3, 4) However, the machine methods normally available usually fail to meet requirements (2) and (3), while acid sawing is so time-consuming that it is impracticable when a large number of specimens is required. A drawing of an apparatus to meet these requirements is shown in the figure.



A device for cutting single-crystal rods

The apparatus is mounted on a $\frac{1}{2}$ in. thick steel baseplate *A*. This could be of any convenient size; in the actual model it is 8 × 6 in. The steel cutting anvil *B* is also $\frac{1}{2}$ in. thick and rotates about a retaining pin *C*, which bolts it to the baseplate *A*. The top surface of this pin is level with that of the anvil, and this region is the one used for cutting the crystal.

Rotation of the cutting anvil by 55° to left or right al the centre-line *DC* is possible. Its position is indicate index *G* on scale *E*, it can be clamped securely by a passing through slot *F* and held with a wind-nut under baseplate.

The $\frac{3}{8}$ in. diameter crystal is held in place along the cen line of anvil *B* by a similar but shorter $\frac{1}{2}$ in. thick block This clamping block has a 90° groove in its bottom fac secured to anvil *B* by set pins *I* and is located by dowe The crystal is cut by a jeweller's saw which is held against hardened steel edges *K*.

Before work is done on the crystal a master reference is scribed along one side parallel to the major axis. crystal is then clamped to the anvil and a normal cut ta with index *G* on the zero of the scale *E*. Worked met removed by etching and the orientation deduced fron Laue back-reflexion photograph. Further cuts through crystal parallel to any plane (*hkl*), necessitates, in gen azimuthal rotation of the rod around its longitudinal and also about point *C* in a horizontal plane. Thus required plane becomes parallel to cutting edges *K*.

The azimuthal rotation is accomplished with the aid protractor *L* and a Perspex pointer *M*. With index *G* zero, the protractor is fastened to the base by two accura located brackets *N*, which ensure that its centre coinc with that of the crystal and its diametral line is paralle the baseplate. The Perspex pointer fastens to the cry by a modified Terry clip, and the end of the pointer nea the crystal alines with the master reference scratch. observing the other end of the pointer on the protra scale the azimuthal rotation can be controlled.

When the azimuthal rotation has been accomplished, crystal is clamped firmly in place and the pointer and tractor removed. Any horizontal rotation required is effected by moving index *G* along scale *E* and then secu the anvil with the wing-nut. The block *O* on the under of the baseplate allows the unit to be clamped in a vice ease of cutting.

Both scales on the instrument can be readily set to $\frac{1}{2}$°, the overall accuracy attainable by the device is generally better than 2°. Several factors combine to keep the fig high; the spots on the back-reflexion Laue photograph u a 1 mm collimator and a film-specimen distance of 3 cm often of the order of 1°, measured on Greninger's cha while if the optical etch-pit method is used, it is well kn that crystal planes revealed by etching may often be as m as 2° from their true lattice positions.(5) Again the sections are usually mounted in plastic mounts for final and taken through emery papers and etched before f examination, and this involves some error.

An accuracy of 2° is often sufficient for some types of wo for higher accuracy the preliminary cutting must be follo by diffractometer techniques such as those already refer to.(1, 2)

REFERENCES

(1) Walker, J. G., Williams, H. J., and Boyorth, R. *Rev. Sci. Instrum.*, **20**, p. 947 (1949).
(2) Sato, H., Getsko, J., and Hickman, W. E. *Rev. Instrum.*, **28**, p. 58 (1957).
(3) Collins, J. A., and Mathewson, C. H. *Trans Ar Inst. Min. Metall. Engrs*, **137**, 1940, p. 150, T.P. 1 (1940).
(4) Maddin, R., and Asher, W. R. *Rev. Sci. Instrum.*, p. 881 (1950).
(5) Goss, A. J. *J. Sci. Instrum.*, **30**, p. 283 (1953).

Preparation of fine wires for metallographic examination

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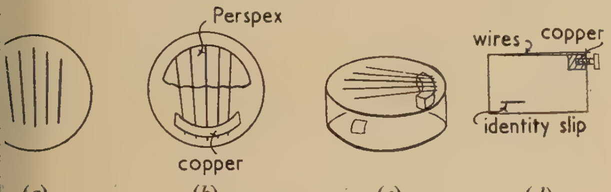
[*Note received* 23 *October*, 1957]

the course of an investigation into the recrystallization of gsten wire, many hundreds of specimens had to be mined, and it became necessary to develop a rapid method mounting these specimens for electrolytic polishing and ing. The following procedure was found to be simple convenient and could be handled by a semi-skilled stant.

number of wires forming a suitable group were laid wise in a normal mounting die anvil as in the figure (*a*) a piece of Perspex laid over the splayed ends, the other s being covered with a strip of soft copper (*b*). The die nder was slipped over the anvil and sufficient mounting vder was poured in; this was lightly pressed and an entification slip put in place followed by a further layer of vder. Mounting was then carried out in the usual way (*c*). wires were ground to reveal roughly diametric sections then a viscous coat of Perspex in solvent was flowed r the copper and allowed to dry, after which the pellet retreated in the mounting press. This left the wires osed, but the copper protected, so that electrolytic treatnt of the wires was not affected by its presence. Finally a ninal was screwed into the block making contact with the per (*d*). Fine grinding and rough polishing were carried with papers and diamond dust, completing the polishing trolytically.



(*a*) (*b*) (*c*) (*d*)

Mounting sequence

Vith tungsten wire, polishing was effected in 2 min in 1·5% stic soda at 20° C and at 10 V. To etch, the mounts were nsferred to a bath of 0·75% caustic soda where polishing at first continued for 15 s at 10 V and then by switching a 0·75 V supply, the wires were etched with very clear, roducible results.

he author wishes to thank Dr. J. A. M. van Moll, and the ectors of Mullard Ltd., for permission to publish this note.

economical safe hand-controlled device for raising small quantities of liquids by compressed air

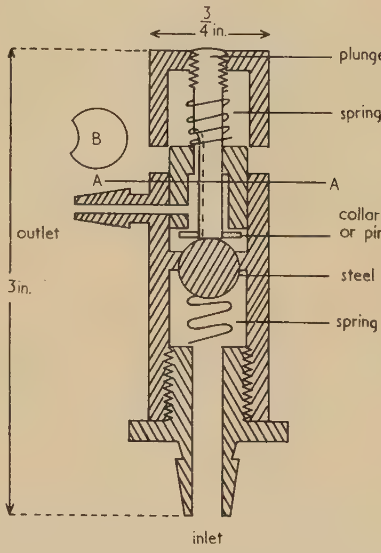
y W. S. Sebborn, B.Sc., A.R.I.C., Research Laboratories, Kodak Ltd., Wealdstone, Harrow, Middlesex

[*Note received* 21 *October*, 1957]

a chemical laboratory or dispensary, it is frequently essary to raise small quantities of liquid intermittently m a closed container to a vessel at higher level. It is convenient to use compressed air for this purpose, but the process may be dangerous, especially when corrosive or poisonous liquids are being handled.

The device described allows this operation to be accomplished in a safe and economical manner: compressed air may only be admitted to the liquid container while finger pressure is applied to the valve, and immediately finger pressure is removed, the air supply is shut off and pressure within the container is released.

The construction of the apparatus is shown diagrammatically in the figure. The body is a cylinder of brass with a wall $\frac{1}{8}$ in. thick, fitted with an inlet and an outlet, between which is a valve formed by a circular orifice closed by a spring-loaded steel ball. The spring normally presses the ball into the orifice and prevents flow of air between inlet and outlet; when pressure is applied to the ball so as to compress the spring, the valve opens, and flow takes place. The valve is operated by means of a cylindrical plunger, grooved along two-thirds of its length as shown in the diagram. This groove ensures that when the plunger occupies the normal "closed" position, there is free communication to the atmosphere from the outlet side of the valve.



Cross-section of valve

B, section of plunger through *AA*, enlarged.

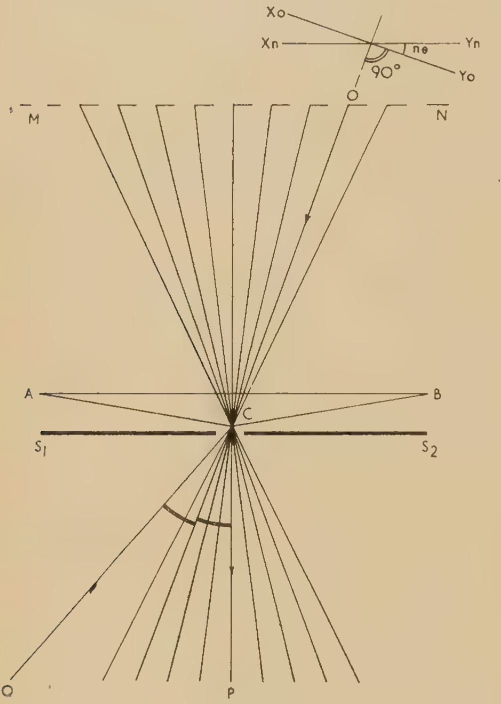
The valve has been used successfully in routine analytical chemistry for filling burettes with standard solution from a stock bottle placed at floor level, and in conjunction with an automatic pipette of conventional design for dispensing premeasured identical amounts of liquid. In these instances, the maximum height to which the liquid was lifted was six feet. In order to obtain a reasonable rate of filling, an air pressure of 5 lb/in.^{2} was found to be suitable, but by a suitable choice of spring size and dimension of groove in the plunger, a wide range of operating conditions may be successfully dealt with.

The device as illustrated may also be operated by pressure with the foot: in this instance it may be mounted on the floor at a convenient angle. This is especially convenient for repetitive dispensing procedure where both hands of an operator might be occupied.

Correspondence

On the optical properties of a biprism combined with a coarse grating

In continuation of our note published on p. 464 of the November 1957 issue of this journal we wish to report that the optical arrangement described there can be modified by substituting a biprism in the place of the grating held near the telescope and removing the object glass of the telescope (see figure).



Optical arrangement of biprism and grating

The bands observed in the focal plane of the eyepiece are equidistant, clear and well defined when: (1) the common refracting edge C of the biprism is parallel to the line the grating and to the slit of the collimator; (2) the p face AB of the prism is parallel to the plane MN of grating; (3) only the rays emerging near the common e are allowed to pass through by placing stops S_1 and S_2 c to the prism; and (4) the slit is kept wide.

The bands are formed at points where rays from succes transparent elements of the grating undergo refraction at common refracting edge C of the prism and intersect focal plane of the eyepiece. One such ray proceeds from grating element O, gets refracted at C into two rays w intersect the focal plane of the eyepiece at P and Q. As source slit of the collimator is wide numerous plane w fronts in a variety of orientations are incident on the grat Hence a number of plane wavefronts $X_0 Y_0$, X $X_2 Y_2 \dots X_n Y_n$ are incident at O, their planes being incl at angles 90°, $(90 + \theta)$, $(90 + 2\theta) \dots (90 + n\theta)$ respec with the direction CO, where $\theta, 2\theta, 3\theta \dots n\theta$ are the an of diffraction of the first, second, third ... n^{th} order diffra wavefronts respectively. Hence the zero order diffra wavefront of $X_0 Y_0$, first order of $X_1 Y_1$, second orde $X_2 Y_2 \dots n^{th}$ order of $X_n Y_n$ are incident normal to OC will be propagated in the direction OC increasing the inter of the ray considerably. No interference between the vi tions propagated along OC is possible since the incident p wavefront originates from noncoherent sources. For reason the visibility of the bands does not change when distance D apart of the grating and prism is altered. angle subtended by successive bands at the prism is equa Δ/D where Δ is the width of the grating element.

A displacement of the grating parallel to itself by r gra elements, causes r bands to move across the cross-wire. grating-biprism combination has therefore optical prope similar to a pair of identical coarse gratings and can be to similar uses. One of these uses is described in the referred to at the beginning.

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Trivandrum.

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C. A. VERGHESE

[19 November, 195

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impr products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Grating type Ebert scanning spectrophotometer. Hilger and Watts Ltd., 98 St. Pancras Way, London, N.W.1.

The JAco–Ebert grating type scanning spectrophotometer has a first order reciprocal linear dispersion of 16 Å/mm at the exit slit, with a minimum resolution of 0·2 Å. It is a low-priced instrument easily adapted for use as a flame spectrophotometer. Incorporated into the JAco Model 8200 is a linear wavelength scanning mechanism which requires only a simple Veeder–Root counter to indicate first-order wavelength. A built-in eight-speed motor drive permits variable speed scanning in either direction, with manual drive also provided. The JAco–Ebert scanning spectrometer serves as an excellent source of narrow band-pass, high inter monochromatic light, and is well suited for investigat such as, for example, band structure, isotope abund ratios, or studies of spectral energy distribution. instrument is compact, measuring only 18 in. long.

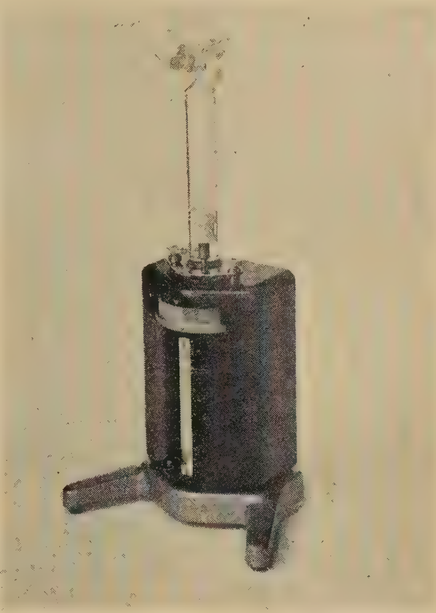
The JAco–Ebert scanning spectrometer is available wi choice of either direct recording of spectral intensities or absorption studies. The first is a high sensitivity system plotting absolute intensity against wavelength, using a s chart recorder. The second system is used for ratio record where the ratio of the total source intensity, relative to spectral intensity, is plotted on a strip chart recorder.

ourteen-channel magnetic tape recorder. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A.

new tape recorder has been designed to handle amplitude-iodulated, frequency-modulated or pulse-width modulated gnals. The system is intended for use in wind tunnel, ngine test stand and other research studies where high-speed cquisition of large amounts of data is required. The freuency range covered is from d.c. to 100 kc/s at input levels om 0·25 to 25 V r.m.s. Fourteen individual tape tracks r the simultaneous recording of separate signals on 1 in. pe are provided. The system takes reels up to 14 in. iameter, has a capacity of 5000 ft of 0·0015 in. tape and is pable of operating at tape speeds of $1\frac{7}{8}$, $3\frac{3}{4}$, $7\frac{1}{2}$, 15, 30 and 0 in/s. Other tape widths can also be accommodated. Five ositive action push-button controls are grouped on the ont panel to facilitate operation. The re-wind time for 00 ft of tape is about 5 min.

iston burette. B. &. K. Laboratories Ltd., 59 Union Street, London, S.E.1.

he illustration shows a burette manufactured and designed by letrohm Ltd., Switzerland, to simplify the process of titraon. Essentially it consists of an inverted glass tube burette ith a three way stop cock. Inside the glass tube slides a eflon plunger which can be actuated by means of a screw iechanism controlled by a knurled and graduated disk rojecting from the front of the lower plastic housing. To perate the burette the cock is first turned to connect to a orage bottle and a knob on the base pressed down. The urette then automatically fills in 2 s. For titration the ock is turned to its other position and by turning the nurled disk the piston is forced upwards and expels the quid. The amount expelled is read off on the vertical scale and the graduated disk. The linear scale is graduated in ml. and the disk in 0·01 or 0·02 ml. for the 10 or 20 ml. capacity burettes respectively. Since the space between the plunger and cock is always full, errors due to the variations in shape of a meniscus or drops adhering to the walls of the tube are eliminated.


Piston burette

A model with motor drive is also available and in this case titrant can be delivered accurately in quantities of 1% of the burette volume by operating a press button switch.

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Thermo-couple potentiometer. Doran Instrument Co. Ltd., roud, Gloucester. Leaflet 112 describes a thermo-couple tentiometer which has been introduced to meet the demand r a light and portable unit, and which is claimed to have accuracy and performance equal to that of the much rger and more expensive potentiometers previously available.

"Griffin raybox." Griffin and George Limited, Ealing oad, Alperton, Wembley, Middlesex. A leaflet (P2022) scribes the "Griffin raybox" which provides a simple means producing single or multiple light rays for use in elementary tics. A useful list of accessories available as extras is also tailed.

Analogue computer and transducers. Evershed and Vignoles d., Acton Lane Works, Chiswick, London, W.4. Speciation sheets have just been issued covering a number of ansducers, the associate power units, and a simple analogue mputer. The transducers covered are for flow, pressure, fferential pressure and level. Being produced in support these sheets are further sheets of a more technical nature vering the instruction and maintenance aspects of each transducer. The former sheets will be known as "Specification sheets", prefixed "SS", and the latter sheets as "Instruction and maintenance sheets", prefixed "IM".

Amplifier. Beckman Instruments Inc., 325 Muller Avenue, Anaheim, California, U.S.A. Bulletin 3003 describes the model WN amplifier which is a high gain, broad band, chopper stabilized, precision amplifier designed specifically for analogue computation and for amplification of low level d.c. signals such as strain gauge, transducer, or thermocouple output.

Microwave test equipment system. Polytechnic Research and Development Co., Inc., 202 Tillary Street, Brooklyn 1, N.Y., U.S.A. The latest issue of "PRD reports" features an illustrated technical paper entitled "Antenna pattern instrumentation". This paper describes a complete microwave test equipment system for antenna pattern measurement in the frequency band from 1000 mc/s to 10 500 mc/s. Discussed in detail are the various components of the system, including transmitters, heterodyne frequency meter and recording receiver.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

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Associates: L. Alpin, M. H. Alston, A. J. Apostolakis, A. C. L. Barnard, C. Bristow, D. E. Bromley, K. Burrows, G. E. Cain, R. V. Coates, A. R. Collett, M. G. Davies, W. G. Davies, N. E. Dixon, J. R. Drabble, R. R. Gardner, A. Garnham, E. V. Gilby, H. W. Gosling, G. Haigh, J. K. Hargreaves, E. A. Iredale, G. W. Keeling, E. Kendrick, G. B. Marson, J. V. Major, W. W. Mapleson, W. G. Mayo, E. A. Mussett, T. P. Newcomb, A. C. Newns, E. Nicholas, E. Norcross, F. E. L. Parsons, A. R. Payne, E. R. Pike, W. E. Ribchester, E. Rowlands, K. Scott, J. S. Sivyer, L. R. Thompson, R. Ueda, G. W. Verow, E. T. Wait, R. W. Waldron, R. H. Whiddington, W. F. Williams, K. Worthington.

Fifty Graduates, ninety-four Students and four Subscribers were also elected.

Instruments, Electronics and Automation Exhibition, 1958

The Instruments, Electronics and Automation Exhibition, to be held at Olympia, London, from 16–25 April next, will show the latest advances in scientific instruments—laboratory, industrial and medical, automation and industrial control equipment, telecommunications, radar and navigational aids, computers and many other applications of electronics and instrumentation.

The exhibition is promoted and actively supported by the following Associations: The British Electrical and Allied Manufacturers' Association, The British Industrial Measuring and Control Apparatus Manufacturers' Association, The British Lampblown Scientific Glassware Manufacturers' Association, The Drawing Office Material Manufacturers' and Dealers' Association, The Scientific Instrument Manufacturers' Association of Great Britain Ltd. and The Electronic Engineering Association.

Admission to the exhibition will be by tickets to be distributed by the exhibiting firms or upon payment of 2*s.* 6*d.* at the door; it will be open from 10 a.m. to 6 p.m. daily, except on Friday, 18 April, and Wednesday, 23 April, when the Exhibition will remain open until 9 p.m. There will be lectures each day on subjects relative to the exhibition.

Nuclear engineering monographs

A new series of monographs on nuclear engineering subjects has been issued under the general editorship of Mr. W. K. Mansfield, of the Nuclear Engineering Laboratory, Queen Mary College, London. The monographs are intended for university and technical college students, research assistan and qualified technicians who require a broad understandi of those topics of nuclear engineering outside their own fie of study. The depth of treatment in the specialized wor currently available is often too great and the cost too hi for this category of reader and in producing this relative inexpensive series in association with their monthly journ *Nuclear Engineering*, the publishers have attempted to me the requirement of low cost and at the same time provide broad treatment ranging from elementary principles to up-t date summaries of more advanced theories. The first thr titles received are *Elementary nuclear physics*, by W. Mansfield (price 10*s.* 6*d.*); *Nuclear reactor theory*, by J. Syrett (price 12*s.* 6*d.*); and *Reactor heat transfer*, by W. Hall (price 10*s.* 6*d.*). The monographs are published Temple Press Books, Bowling Green Lane, London, E.C

User-specification for high-temperature X-ray diffracti powder cameras

The X-ray Analysis Group of The Institute of Phys announces that a panel of its Equipment Sub-Committ has completed the preparation of a user-specification deali with the design of X-ray diffraction cameras for the examin tion of polycrystalline specimens at high temperatur Copies of this specification may be had by any interest persons on application to Dr. E. G. Steward, Honora Secretary, Equipment Sub-Committee of the X-ray Analy Group, Research Laboratories, The General Electric C Ltd., Wembley, Middlesex.

Erratum

We have been asked to point out that the work describ in the paper by P. G. England and H. W. Jones, wh appeared on pp. 66–68 in the February issue of this *Journ* was carried out at the Culcheth Laboratories, U.K.A.E. (I.G.), Warrington, Lancashire.

British Journal of Applied Physics

Contents of the April issue

SPECIAL ARTICLE

The mechanical wear of metals. By W. Hirst.

ORIGINAL CONTRIBUTIONS

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Beam temperature, discharge lag and target biasing in some television pick tubes. By B. Meltzer and P. L. Holmes.
An electrical analogue method of predicting the permeability of unsatura porous materials. By M. C. Probine.
A sintered nickel matrix cathode. By R. W. Fane.
The evaporation of sprays. By R. T. Jarman.
Measurements on the air-nuclei in natural water which give rise to cavitat By K. S. Iyengar and E. G. Richardson.
Measurements of pressure distribution between metal and rubber covered roll By G. J. Parish.
A method for determining ^{24}Na and ^{42}K when present together in liquid samp By M. P. Esnouf.

NOTES AND NEWS

New books
Notes and comments

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Studies in microdensitometry

By W. A. Wooster, M.A., Sc.D., F.Inst.P., and J. A. L. Fasham, Grad.I.E.E., Brooklyn Crystallographic Laboratory, Cambridge

[*Paper received* 27 *June*, 1957]

A discussion is given of some factors which affect all microdensitometer studies on X-ray photographs. The particular problems which affect powder photographs, preferred orientation photographs, single crystal photographs and diffuse reflexion photographs are then considered. The use of a rotating circular stage for the investigation of rings of varying density and the use of an integrating mechanism for the determination of the integrated reflexion in a line or spot are described.

n automatic recording microdensitometer was described by ıe of us$^{(1)}$ and, with some additions, this has been used in e measurements described below. The principal types of -ray photographs considered here are as follows: powder, eferred orientation, single crystal and diffuse reflexion. ertain general features apply to all such photographic udies. The area of the film from which light is collected ıd allowed to fall on the photocell should be limited so that variation in density greater than about 20% occurs in the ld examined at any instant. It is easy to show that if the ain of the photographic film is so large that it is useless to amine an area less than 0·1 × 0·1 mm on account of the ght fluctuations due to the small number of grains in the ld of view, then the diameter of the spot under examina- on should not be less than about one millimetre. If, for ample, the densest part of the spot is 2, the background ing taken as zero, then the maximum variation of density ver 0·1 mm along a diameter may be as high as 1·0. To ustrate the effect of this, let us suppose that one half of the ld of view is of density 1·0 and the other half is of density ·0, then the corresponding X-ray exposures are in the same tio and the mean X-ray exposure corresponds to a density 1·50 over the whole aperture. The light transmitted rough the film is of intensity I and that incident on the film of intensity I_0. Then the density, D, is defined by the lation

$$D = \log_{10} (I_0/I)$$

hus $I = I_0$/antilog D.

For the lighter and darker halves of the area 0·1 × 0·1 mm nder test the reciprocals of antilog D are respectively ·1 and 0·01 and the mean value of these is 0·055. Thus ıe intensity of the light transmitted through the two halves gether corresponds to a density given by

$$D_{mean} = \log_{10} (1/0{\cdot}055) = 1{\cdot}26$$

hus the measured effect corresponds to an X-ray exposure f 1·26, whereas the true value is 1·50. This type of error ecomes greater as the density of the spots increases and also s the diameter of the spots diminishes. For measurement ith a microdensitometer the spots should therefore be as rge as possible and have a range of density which does ot exceed 2·0.

POWDER PHOTOGRAPHS

The factors which can influence the pen-record are as llows: speed of traverse under the scanning microscope, ze of limiting aperture, sharpness of focus of the film at the limiting aperture and the grain size of the film used. Each of these will be discussed in turn.

(*a*) *Effect of speed of traverse under the scanning microscope.* The useful speed of traverse when the film is driven by a synchronous motor is limited by the sharpness of the powder lines and the rate of response of the pen-recorder. In these experiments a pen-recorder having a minimum time of full-scale traverse of 2 s was used. The movement of the wedge on the microdensitometer was faster than this. To take an example, let us suppose the powder line is 0·5 mm wide and reaches a density corresponding to full-scale deflexion of the pen-recorder. The speed of traverse must in this case be considerably less than that which would cause the film to move across half the line width in 2 s, i.e. less than 7·5 mm/min. Thus the broader and, up to a certain point depending on the background density, the less dense the line, the more faithfully can the pen-record describe the density distribution along the film. In Fig. 1 some records are shown of the same lines taken at different speeds of traverse. In this photograph it will be seen that at a slower speed than 1·1 mm/min there is no appreciable change in the record.

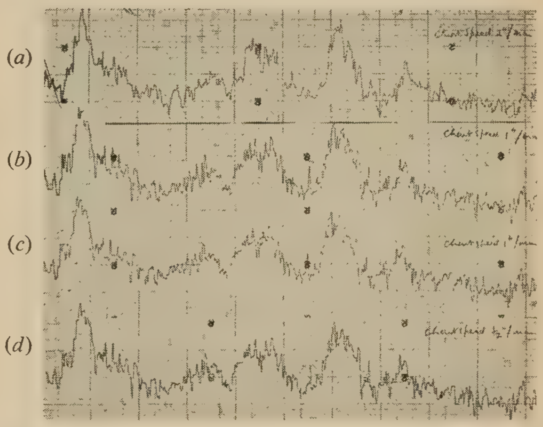


Fig. 1. Records of powder lines made at speeds of traverse of the film: (*a*) 2·2 mm/min; (*b*) and (*c*) 1·1 mm/min; (*d*) 0·55 mm/min. Record (*a*) departs from the true record (*d*). Diameter of powder camera = 19 cm. Range of $2\theta = 35° - 41{\cdot}5°$

(*b*) *Effect of size of limiting aperture.* The size of the limiting aperture can be widely varied, depending on the objective and eyepiece used, without altering the area of the film from which light is collected and measured. In the present discussion the size of aperture referred to is always the area on the film from which light can pass through the actual limiting aperture. There are two conflicting requirements in this work: one is high resolution and the other is smoothness of the record. Narrowing the limiting aperture increases the resolution, but it is not worthwhile to decrease the width of the aperture below about 0·1 mm for Ilford G film. This limit is due to the grain size of the film and is dealt with below. Higher resolution can be obtained only by using a narrower aperture and film of finer grain such as Ilford B or C. Figs. 2 and 3 show the effect of change of aperture size on the record given by a particular line. The differences between the records are not great and when an ink line is drawn through the curves so as to give the mean shape, the change associated with this change of aperture size is relatively small.

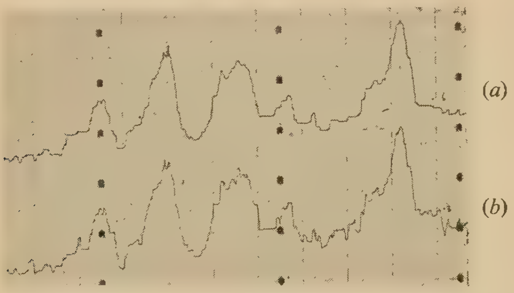


Fig. 2. Records of powder lines taken with different slit widths (at the film). The slit widths were: (*a*) 0·9 × 0·10 mm; (*b*) 0·9 × 0·05 mm

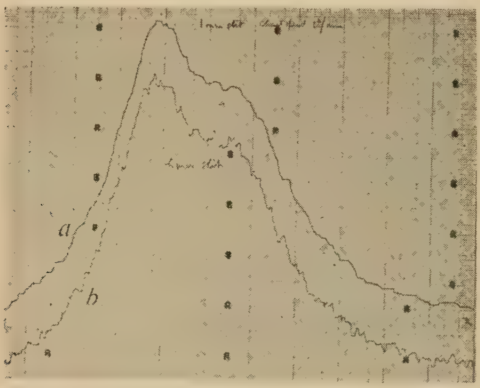


Fig. 3. Record of an unresolved doublet with two slit widths: (*a*) 0·9 × 0·15; (*b*) 0·9 × 0·10 mm. Maximum density above background = 1·5

(*c*) *Sharpness of focus.* There is a temptation to defocus the image of the film in order to diminish the rapid fluctuations of the pen-record. The effect of this is to allow light from a larger area of the film to reach the photocell and therefore to increase the effective size of the limiting aperture. If a smooth line is ultimately to be drawn through the pen-record the fluctuations make relatively little difference and defocusing the image serves little purpose. Fig. 4 shows that the height of the peaks is reduced by defocusing.

(*d*) *Effect of grain size of the film.* The grain size of the film affects the following: exposure time, resolution, useful size of limiting aperture, fluctuations of the pen-record. X-ray film of large grain size requires a shorter exposure to produce a given photographic blackening. The resolution of Ilford G film is such that fine lines and line profiles ca be recorded with the same ease as they can be with Ilfor In Fig. 5 the upper curve refers to Ilford G and the lo to Ilford B film and shows a comparison of a Kα dou taken under otherwise identical conditions on the two ty of film. The fluctuations of the pen-record introduce uncertainty in the correct position of the smooth pen-l which can be drawn on the record. This is sufficiently serio when line profiles are under consideration to make it wor while doubling the exposure and using Ilford B film.

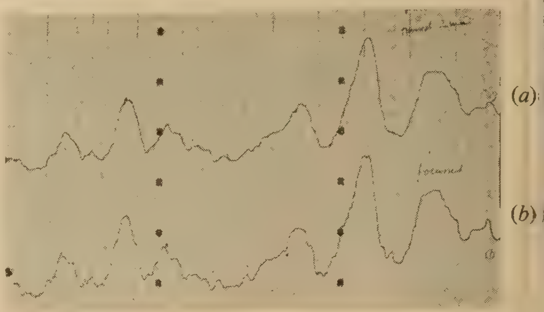


Fig. 4. Record of the same powder lines with: (*a*) micro scope raised 2 mm above normal (focused) positio using a 25 mm focal length objective; (*b*) with microscop focused

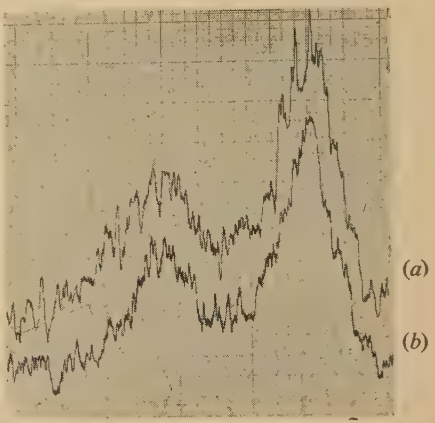


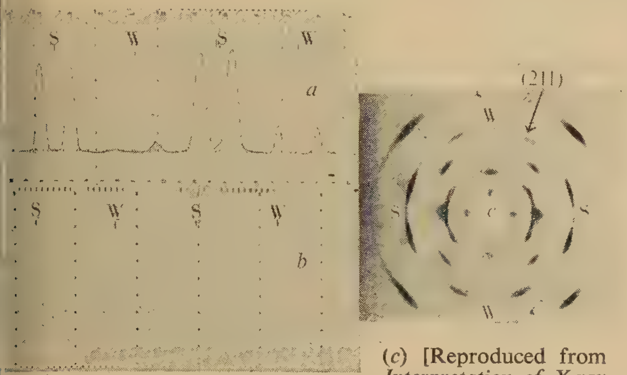
Fig. 5. Record of a Kα doublet on: (*a*) Ilford G (*b*) Ilford B film all other conditions being kept constant Diameter of powder camera = 19 cm. Slit width = 1·0 × 0·10 mm. Separation of $\alpha_1\alpha_2$ peaks = 1·9 mm Maximum density above background = 0·5

PREFERRED ORIENTATION PHOTOGRAPHS

Out of the several possible variants of preferred orientati photographs we shall here discuss two, namely, (*a*) the ty with circular rings of density varying round their circu ference and (*b*) the type obtained with a moving her cylindrical film and oscillating specimen.(2)

(*a*) *Circular rings.* For the study of the variation density round the circular rings obtained on a film norm to the X-ray beam, a rotating circular stage has been add to the microdensitometer. By this means the circumferen of any circular ring can be made to pass at a uniform ra under the scanning microscope and the corresponding dens at each point recorded.

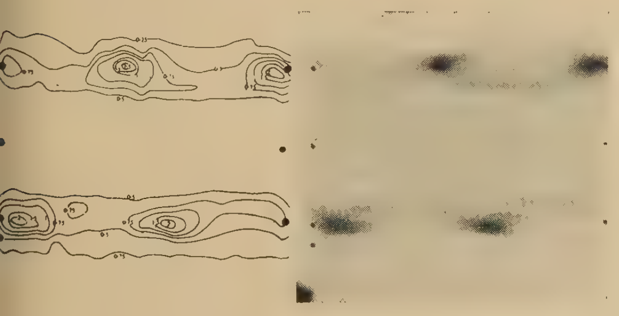
A difficulty arises due to the fact that such rings are seldom ily circular or of the same width at all points. As a result e record obtained with any given radius of the scanned rcle is not truly representative of the density variation round e ring. To overcome this a number of records can be taken th slightly different radii of the scanned circle. Such a set shown in Fig. 6(*b*). By averaging over such curves a presentative distribution of density can be obtained. A etter solution of this problem is attained by giving to the hole circular stage an oscillatory movement along a radius f the circular stage. In this way the darkened circle passes nder the microscope from one side to the other and back gain a great many times during a single rotation. The nvelope of the resulting curves on the pen-record gives the equired density distribution. Fig. 6(*a*) shows the record btained in this way of the same preferred orientation photoraph, Fig. 6(*c*), as is studied in Fig. 6(*b*).



(*c*) [Reproduced from *Interpretation of X-ray photographs*, published by Macmillan and Co., Ltd.]

Fig. 6. Record of the variation of density round the 211 reflexion of a transmission photograph of molybdenum foil: (*a*) using an oscillatory movement along a radius of the circular stage; (*b*) using slightly different radii of rotation with a non-oscillating stage; (*c*) photograph from which the records were obtained. The letters *W*, *S* denote corresponding points on the records and on the photograph

(*b*) *Moving-film preferred orientation photographs.* There re two features which distinguish moving-film preferred rientation photographs from those having only circular ings, namely, the larger area to be examined and the relatively slow rate of variation of density from point to point along the film, Fig. 7(*b*). These differences make it necessary to employ a much higher traverse rate than is normally possible in a powder photograph. To obtain a survey of a film, say 10 × 8 cm in extent, a series of traverses along the 10 cm direction is made with a separation of say 0·5 cm in the 8 cm direction between each traverse. From these sections of the density distribution a contoured map of density, Fig. 7(*a*), is constructed. Such a map is best made in the following way. From an inspection of the records it is decided what contours would be most useful. Horizontal lines are then drawn on the records corresponding to these particular densities. The positions of a particular density along the records are marked on a set of corresponding parallel lines on the map. All points corresponding to the same density are then joined and the contour thus obtained. This process is repeated for each contour in turn.



(*a*) (*b*)

Fig. 7. (*a*) The corresponding contoured density map to the (*b*) moving film preferred orientation photograph. (The background density is taken as zero)

SINGLE CRYSTAL PHOTOGRAPHS

The problem presented by oscillation, Weissenberg, and direct projection photographs is principally the determination of the integrated intensity. If a mechanical integrating device is used then the problem becomes simply that of measuring the density at the centre of each spot. In what follows we shall assume that the integration is to be performed on the microdensitometer itself. For the measurements described below the integration has been carried out by adding to the microdensitometer (*a*) a mechanical system of scanning, involving the movement of the film under the microscope and (*b*) an electrical integrating device giving the line integral of the density over the track scanned. The mechanical scanning is effected by the rotation of a cam which gives a uniform motion to the photographs backwards and forwards over a few millimetres in a direction, say the *y*-direction, while the whole photograph moves at a uniform rate in a perpendicular direction, say the *x*-direction. The rates of movement in the *x*- and *y*-directions can be independently varied since they are controlled by separate gearboxes. The speeds in each gearbox are arranged on a scale of 2. The electrical integration is achieved in the following way. The movement of the measuring wedge is coupled to a potentiometer the output of which drives a low-inertia d.c. motor. The speed of this motor is proportional to the applied voltage over the range 0·1–24·0 V. Thus the total number of rotations of the armature of this motor is proportional to the time-integral of the voltage given by the potentiometer. This number is thus also proportional to the distance-integral of the density along the track scanned.

There are a number of factors which are important in such measurements, namely the accuracy and reproducibility of any one observation, the total time taken to scan one spot, the size and maximum density of the spot and, finally, the arrangement of the spots on the photograph. It is not easy to devise tests by which the accuracy of the measurement can be determined. As a contribution to such a test the following observations were made. Two spots, *A* and *B*, were chosen on a Weissenberg photograph. The diameter of each spot was about 1½ mm. The scanning was carried out along the same track in each measurement but the speed was increased by a factor of two in passing from one line of figures to the next below it in the following table.

The bracketed figures give the values to be expected if those taken at the slowest speed are correct. In the last line the maximum error amounts to 9% for spot *A* and 3% for spot *B*. Spot *A* was as dark as is permissible in these measurements (maximum density about 3).

Another test can be applied by changing the number of traverses in the *y*-direction during a single sweep in the *x*-direction. This was carried out on two spots on a retigraph photograph. The throw of the cam was 4·4 mm and the length of traverse in the *x*-direction was 3·2 mm.

Table 1. *The effect on the total number of revolutions of the integrating motor of changing the scanning rate*

Cam speed (rev/min)	Traverse speed (mm/min)	Number of revolutions: Spot A	Number of revolutions: Spot B	Total time taken (min)
3¾	1	546, 547	156, 156	2·5
7½	2	273, 272 (273)	78, 77 (78)	1·25
15	4	151, 149 (137)	40, 40, 40 (39)	0·63

Table 2. *The effect on the total number of revolutions of the integrating motor of changing the number of traverses in the y-direction*

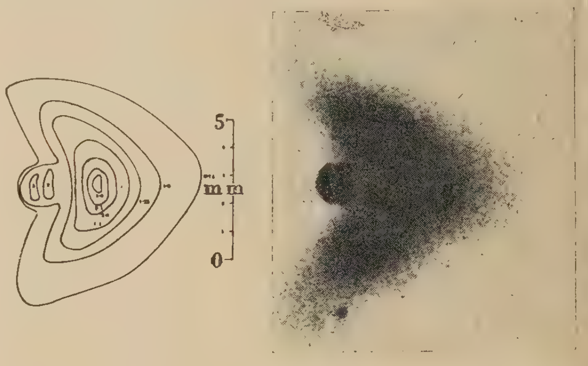
Number of y-traverses	Number of revolutions: Spot A	Number of revolutions: Spot B	Total time taken (min)
5	92, 91, 93	38, 36, 38	0·7
10	93, 94	38, 36, 38	0·7
20	97, 98	38, 37	0·7
40	96, 97, 96	40, 40, 40	0·7

From the above table it will be seen that the measured intensity increases slightly with the number of traverses in the *y*-direction but that the error is probably less than 5% when the number of *y*-traverses is between 10 and 20. The general conclusion from a number of such tests is that a result accurate to 5% can be obtained provided (*a*) that 45 s can be allowed for each measurement, (*b*) that the density at the centre of the spot does not exceed that of the surrounding clear film by more than 2, (*c*) that the spot is not less than 1·5 mm in diameter, and (*d*) that the density of the surrounding background is not greater than 1.

The arrangement of the spots on the photograph is important in relation to the time required for a complete survey of a given set of spots. On a Weissenberg photograph the spots are arranged on U-shaped curves which necessitate an adjustment of the film carriage on the *x*- and *y*-directions for each spot. The direct projection photographs have spots arranged on a series of parallel straight lines and it is therefore possible to move from one spot to the next in the same row simply by resetting the film carriage along either *x*- or the *y*-direction.

DIFFUSE REFLEXION PHOTOGRAPHS

Diffuse reflexion photographs commonly extend over area of 10 × 10 mm and the problem is that of plottin contour map of density over this area. Fig. 8(*b*) shows diffuse spot obtained from a single crystal of lead,[(3)] toget with the corresponding contoured density map, Fig. 8 To obtain the necessary data for drawing such a map au matic records are made of the density variation along a of parallel lines 0·5 mm apart from one another. Lines drawn on the pen-record corresponding to the contours wh are required. From the intersections of these density li with the curves the co-ordinates of points on the contour m having a given density can be determined. For some p poses, e.g. the determination of elastic constants, it is o necessary to draw one or two contours because the m accurate determination can be made from certain particu points on the contour map.



(*a*) (*b*

[Reproduced from *Acta Crystallographica*]

Fig. 8. (*a*) Contoured map of density variation over th diffuse spot. The innermost contour corresponds to density of 3 and the outermost contour to one of 0·75 the background being taken as zero. (No "skew" o "divergence" corrections have been made.)

(*b*) Diffuse X-ray reflexion photograph obtained wit a single crystal of lead in the neighbourhood of the 40 reflexion, from which the contoured map was obtaine

REFERENCES

(1) Wooster, W. A. *J. Sci. Instrum.*, **32**, p. 457 (1955).
(2) Wooster, W. A. *J. Sci. Instrum.*, **25**, p. 129 (1948).
(3) Prasad, S. C., and Wooster, W. A. *Acta Cryst.*, p. 38 (1956).

The construction and testing of a "universal" light scattering apparatus

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The construction and testing of a light scattering apparatus, suitable for the investigation of macromolecules in solution has been described. By the use of a parallel beam of light through the scattering solution, calibration anomalies have been removed and the apparatus can be calibrated by, or utilized for scattering measurements on, liquids of any refractive index.

a previous paper from this laboratory,(1) a simple yet ective light scattering apparatus was described and its plication to the general investigation of macromolecules solution was reported. Whilst the apparatus was highly tisfactory for scattering systems of relatively constant fractive index, anomalies occurred when, for example, libration of the apparatus for aqueous scattering solutions as attempted using a liquid of different refractive index. a later paper,(2) it was shown that this anomaly disappeared hen the convergent light beam of the early apparatus was placed by a well-defined parallel beam. This paper scribes the new apparatus, incorporating the parallel beam d other related modifications, and deals with testing and plication to typical systems.

1. INCIDENT BEAM (FIG. 1)

Light from a medium pressure mercury lamp *A* (125 W lazda MB/V or 80 W Philips MB/U), operated from a rge (2·5 kVA) constant voltage transformer, was focused condensing lens *B* (focal length 7·3 cm and aperture 0 cm) upon the slit *D* (7 mm high and 3 mm wide), itself laced at the focal point of the good quality collimating ns *E* (focal length 16 cm, and aperture 6 cm). The parallel eam thus produced was defined by two field apertures *F* d *G*, *F* being fixed in the wall of the light-tight box surounding the cell bath *H*, and *G* being close to the cell and uilt in to the bath. Only the central portion of the beam, mm high and 4 mm wide, was utilized. The 5461 A line f the mercury spectrum was isolated by a Wratten 77 A lter and the 4358 A line by a combination of Ilford 809 nd 601 filters (*C*). All elements in the incident beam, cluding the cell bath, were mounted securely upon a sturdy ptical bench.

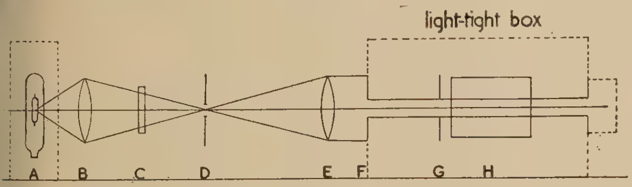

Fig. 1. Incident optical system (elevation)

2. CELL BATH (FIG. 2)

Rectangular cells, of internal dimensions 5 × 5 × 1 cm, ere mainly used. In the later stages of the work such cells, hose component parts were sealed together by means of black opaque cement, became available* and since internal multiple reflections within the walls of the cell are thus largely reduced, such cells are now almost exclusively used. In the light of previous experience (and particularly to minimize reflection troubles) it was necessary to design some type of cell bath which would not impair the well-defined nature of the incident beam nor introduce other optical complications. The internal surfaces of the bath also had to withstand a series of organic solvents in addition to aqueous fluids.

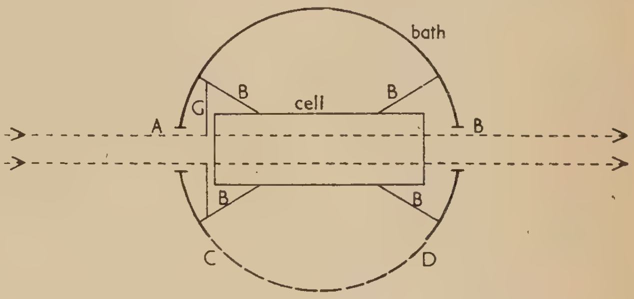

Fig. 2. Cell bath (plan)

Brass tube of internal diameter 7·5 cm was used for the 5 cm vertical walls of the bath. Flat surfaces were machined to take plane entrance and exit windows *A* and *B* (2 × 3·5 cm) which were cut from microscope slides of good optical quality. The observation window *C–D* (11 cm in length and 1·6 cm high) was made from a 3·5 cm length of striation-free glass tubing whose internal diameter coincided with the external diameter of the brass tubing. Sealing of the windows to the brass tube was performed by means of a dental cement (Alston oxyphosphate) coated with Araldite D (combined with hardener 951). More recent experience indicates the suitability of normal Araldite (2-tube) for this purpose. As yet the bath has been utilized at room temperature only but modification for use as a variable temperature thermostat is contemplated.

A parallel beam of light incident upon plane entrance window *A* proceeds unchanged through the bath liquid, through the rectangular cell and out through exit window *B*. Further, since the scattering volume was chosen to be small (see later) and the thickness of the cell is a small fraction of the diameter of the bath, it follows that light scattered at any angle with respect to the incident beam strikes the bath wall at normal incidence and so emerges undeviated. This will be approximately true even if the bath liquid differs from the cell liquid in refractive index, and accurately so in the absence of refraction effects.

The solution cell was held precisely in the bath by means of a radial baffle system, similar to that already described,(1) designed to prevent stray reflected light from reaching the receiving optical system. The vertical baffles are held between two horizontal circular brass plates in which suitable grooves allow radial motion of the baffles. By means of locating pins the lower plate fits precisely into the bath and supports the cell, while the upper plate resting upon the vertical bath walls contains a slot through which the cell just passes. The second field aperture *G* (Fig. 1) is also held by the baffle system.* All metallic parts of the cell bath and baffle system were chemically blackened to produce a matt non-reflecting finish by means of the R.E.L. process, details of which were kindly provided by the British Scientific Instruments Research Association. Such a finish is required when organic solvents are to be used as bath liquids but, if only aqueous liquids are to be used, then a dull optical black is preferable.

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* From C. J. Whilems Ltd., Ilford Optical Works, Barkingside, ssex.

3. RECEIVING SYSTEM (FIG. 3)

An R.C.A. photomultiplier (type IP.21) was used, in accordance with the recommendations of Engstrom,(3) as detecting device and the receiving optical system was designed to give unit magnification of the scattering volume at the cathode *D*. Lens *B* of focal length 5 cm and aperture 1·5 cm was preceded by a 1 cm diameter circular aperture *A*. A slit *C*, 10 mm high × 4 mm wide, immediately preceded the multiplier, both being contained in a light-tight housing, base and leads being highly insulated. As designed, the photomultiplier received light from a volume well within the boundaries of the parallel beam as it traversed the cell and this was true even when considerable refractive index differences between cell and bath liquids occurred. Further, to ensure that the sensitivity did not vary, the same part of the cathode surface received the scattered light whatever the angle of observation, as was confirmed by replacing the multiplier tube by a ground glass screen and visual observation (see later also). The receiving optical system as a whole rotates about a vertical axis through the centre of the solution cell and (with a suitable neutral filter) can be used to collect the transmitted beam. The single support holding the cell bath on the optical bench was also used to provide the axle by which rotation of the receiving system occurred. The angle θ made by the axis of the receiving system with the incident direction was indicated by a pointer *P* moving over a circular scale mounted just below the cell bath. The state of polarization of the scattered light was investigated by using a piece of Polaroid in front of aperture *A* in such an orientation that light with electric vector vertical or horizontal was transmitted.

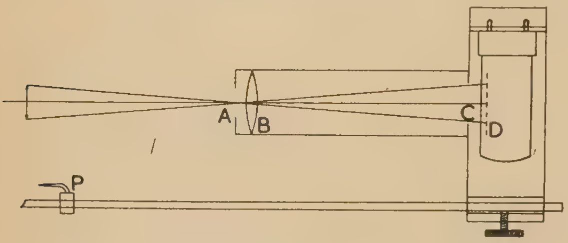

Fig. 3. Receiving system (elevation)

Since the substitution of a parallel for the earlier convergent incident beam resulted in loss of intensity, it was necessary to devise some amplification between the multi tube and the galvanometer (Tinsley type 4500 A). A st cathode follower current amplifier with the circuit show Fig. 4 was designed by Dr. J. A. Sirs and used for this pose. Dry batteries (Ever Ready type 61) provided voltage for the nine-stage multiplier, 90 V being applied the cathode and to all dynodes except the last where 108 was used. Two EF.37 A pentode valves, connected cathode followers and balanced one against the other, w the main elements of the amplifier. The photomultipl output was developed across a 10 MΩ, high stability resist R_1, and applied to the grid of valve K_1 which was operat under anode and grid voltage conditions such that the g current was very small ($<10^{-11}$ A). Valve K_2 acted as balancing element, compensating for drifts in the heater a anode voltages; its grid potential could be varied by means the rheostat R_5 in the voltage-dropping resistance cha The difference in current through the two valves was through variable resistor R_3, operated as a sensitivity contr to the mirror and scale galvanometer, whose deflexions we measured. At the input grid, the amplifier was stable ±1 mV, a negligible fraction of the signal strength obtain by using a high value for R_1. With a response time of 0· the overall noise level was better than 1% of the measur deflexions. Amplification with a high degree of linear (because of the feed back action) and with a factor of 1 was achieved without significant instability.

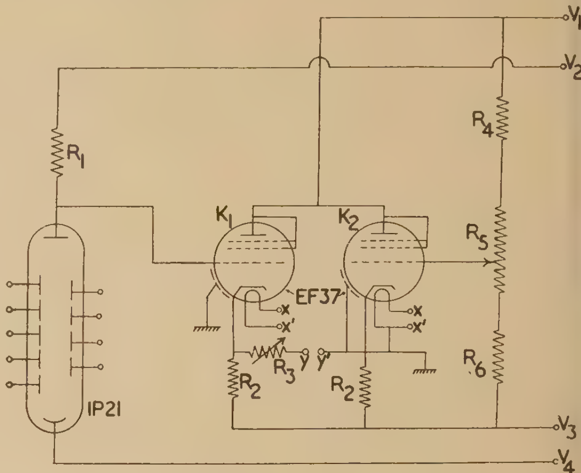

Fig. 4. Cathode follower amplifier circuit

R_1 = 10 MΩ
R_2 = 120 kΩ
R_3 and R_5 = 20 kΩ
R_4 = 50 kΩ
R_6 = 39 kΩ

V_1 = 954 V
V_2 = 918 V
V_3 = 882 V
V_4 = 0 V
XX' = 6 V accumulator
YY' = galvanometer

Mercury lamps varied somewhat in behaviour, but a go lamp caused no visible rapid fluctuations in light intensity judged at high galvanometer deflexion.† Gradual chang in light intensity and in the amplifier were overcome by t use of stable working standards, made from blocks Transpex and glass with suitable scattering properti (Blocks used had effective turbidities of $4\cdot5 \times 10^{-3}$ a $1\cdot5 \times 10^{-4}$ cm^{-1} respectively.) These were cut and polish to fit accurately into the cell holder and all galvanome deflexions from scattering solutions were measured as rati

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* Following more recent work, Mr. C. B. Richards has suggested the use of blackened shielding tubes between the entrance window and the cell and between receiving system and bath window to ensure that incident light does not reach the receiving system.

† On the other hand, fluctuations of the galvanometer in t case of a poor lamp were not due to current fluctuations (<1 500) but rather to arc movement at constant current.

(corr)] to the block deflexion observed immediately before after. Such ratios, accurate to 1 to 2% according to the ensity of scattering, for Rayleigh scattering systems at = 90° are proportional to the turbidities, τ, of the solutions = C. I_{90} (corr)] where C is the calibration constant, d calibration was achieved and repeatedly checked by the of solutions whose turbidities could be obtained spectro- otometrically.(2)

4. TESTING

Before testing as a light scattering instrument, it was ential to confirm the geometrical symmetry of the bath and eiving system. This was performed by using the orescence from a very dilute fluorescein solution in the l, excitation being caused by mercury blue light. A green er in front of the receiving system allowed passage of orescent light but not stray blue light. Fig. 5 contains a ot of intensity (corrected to constant volume by sin θ) ainst angle. Within experimental error this plot is a rizontal line for $\theta = 40°$ to 140°, and the geometrical nmetry of the apparatus is thus satisfactory. Nor can the nsitivity of the multiplier vary with angular position (see ction 3).

Purified toluene and carbon disulphide were used to test absence of spurious reflections. Just before use, each uid was filtered through a no. 5 sintered glass disk. tensity envelopes ($\lambda = 5461$ Å), corrected by the sin θ lume factor only are shown in Fig. 5 and, at the low level scattering shown by both liquids, the absence of irregu- rities demonstrates freedom from reflexion troubles. evious work(1) also gave this type of plot which deviates arkedly from that for a Rayleigh-type scattering system ch as the colloidal silica suspension, Ludox. In obtaining e plot for Ludox shown in Fig. 5, it was necessary to ultiply experimental readings by $\sin\theta/(1+\cos^2\theta)$, the s$^2\,\theta$ term (without any numerical factor) being required to rrect for the presence of light with horizontal electric ctor which occurs in directions other than $\theta = 90°$. It ust be concluded that considerable depolarization at = 90° occurs in the cases of the organic solvents.

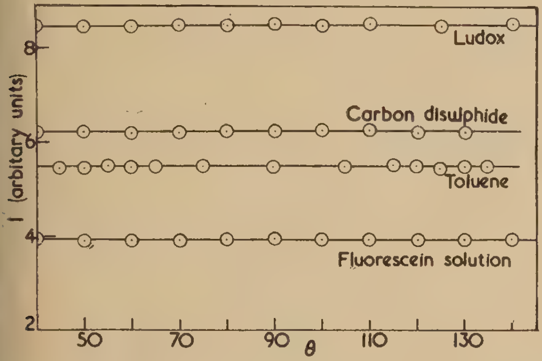

Fig. 5. Intensity envelopes for various liquids; scattered intensity/unit volume is plotted as a function of the angle with the incident beam. Experimental intensity readings were corrected to constant volume by multiplying by sin θ, except in case of Ludox where factor $\sin\theta/(1+\cos^2\theta)$ was used

The calibration of the apparatus and its application to solutions of standard macromolecular materials has been discussed elsewhere.(2) In particular it was clearly demonstrated that the same calibration constant (within ±1%) was obtained whatever the refractive index of the calibrating liquid. It follows conversely that the same calibration constant can be employed to assess the scattering from solutions of varying refractive index so that, in this sense, the apparatus is "universal." A typical Zimm(4) plot for polystyrene IV (distributed by the International Union of Chemistry) in methyl ethyl ketone is shown in Fig. 6. The plots as a function of $\sin^2\theta/2$ (constant concentration) and of concentration (constant angle) are smooth and extrapolation satisfactory. The molecular weight value yielded by the intercept on the ordinate axis is 123 000, somewhat higher than the mean value quoted by Frank and Mark(5) (110 000), but within the range obtained by other workers. In general an accuracy of ±2% in the final molecular weight can be expected.

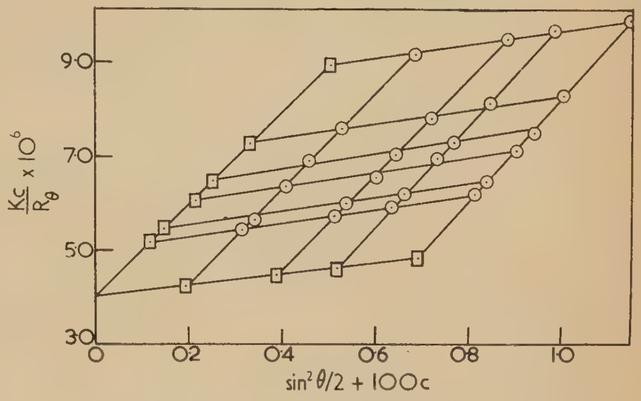

Fig. 6. "Zimm" plot of Kc/R_θ against $\sin^2\theta/2 + 100c$ for International Union polystyrene IV in methyl ethyl ketone. c is concentration in g/ml, K is an optical constant and R_θ, the Rayleigh ratio for angle θ

5. ACKNOWLEDGEMENTS

We are grateful to Dr. J. A. Sirs for the design of the amplifier, to Mr. L. Saggers for making most of the apparatus, to Corning Glass Works for the glass used in a working standard and to the British Scientific Instruments Research Association for details of the R.E.L. process. One of us (W. J. H.) is indebted to the British Rayon Research Association for a research grant.

REFERENCES

(1) Goring, D. A. I., and Johnson, P. *Trans Faraday Soc.*, **48**, p. 367 (1952).

(2) Hughes, W. J., Johnson, P., and Ottewill, R. H. *J. Colloid Sci.*, **11**, p. 340 (1956).

(3) Engstrom, R. W. *J. Opt. Soc. Amer.*, **37**, p. 420 (1947).

(4) Zimm, B. H. *J. Chem. Phys.*, **16**, p. 1093 (1948).

(5) Frank, H. P., and Mark, H. *J. Polymer Sci.*, **10**, p. 129 (1953).

A compensated moving cylinder viscometer

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[*Paper received* 19 *November*, 1957]

Based on the principle of Lawaczeck's falling cylinder viscometer, a new viscometer has been designed, in which the only measurement to be made is the time taken by the cylinder to move a definite distance, without the necessity of either observing the movement of the cylinder or measuring the densities of the cylinder and of the liquid. The instrument consists of two exactly similar light solid cylinders or cylindrical bulbs moving in similar vertical tubes of slightly larger diameters containing the liquid at the same temperature. The ends of each cylinder are made conical to ensure its coaxial movement in the tube and the cylinders are attached to the ends of a Nylon fibre which passes over a light frictionless pulley. Attached to the same fibre at suitable heights above the cylinders are two similar light weight carriers on either of which riders of equal mass may be placed. When a certain number of riders are placed on one side, the cylinder on that side moves down while the other cylinder moves up with uniform speed, the pulley turning round once in a time T which is directly proportional to the viscosity of the liquid. This result may be used to compare the viscosities η_1 and η_2 of two liquids using the same number of riders and noting the times T_1 and T_2 respectively for a complete rotation of the pulley. $\eta_1/\eta_2 = T_1/T_2$.

The instrument is capable of high accuracy and has the special feature that a knowledge of the density of the liquid is not needed in the calculation of the result.

Lawaczeck[(1)] designed a viscometer operating on the principle of a cylindrical metal bulb falling in the liquid coaxially in a vertical tube of only slightly greater diameter. The time of fall t for a fixed distance S under uniform velocity is given by the relation

$$\eta = k\frac{t}{s}(\sigma - \rho)g \qquad (1)$$

where σ and ρ are the densities of the bulb and liquid respectively and g the acceleration due to gravity, k being the instrument constant.

Bridgman[(2)] employed this method in his classical study of the variation of viscosity of liquids with pressure. Dow[(3)] studied the identical problem relating to mixtures of liquids, and Awbery and Griffiths[(4)] found the viscosity of refrigerants using the same method. Their determinations obviously involved the observation of the actual movement of the bulb, in addition to the measurement of the density of the liquid.

We have effected a modification in this method and designed a simpler viscometer having some special features and advantages.

Let V be the volume of the cylindrical bulb. Multiplying both sides of equation (1) by V

$$V\eta = k\frac{t}{s}(\sigma - \rho)g \times V$$

or

$$V(\sigma - \rho)g = \frac{Vs}{kt}\cdot\eta$$

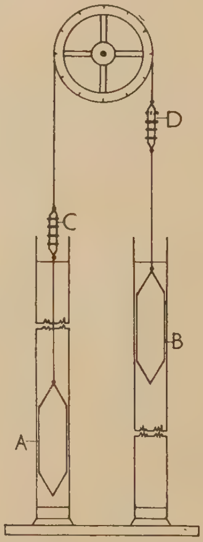
$$= R\cdot\frac{\eta}{t} \qquad (2)$$

where R is another constant.

The left-hand side of the equation (2) is the apparent weight of the cylinder in the liquid which ought to be equal and opposite to the viscous drag P under the condition of the fall with uniform velocity.

Hence $$P = R\cdot\frac{\eta}{t} \qquad (3)$$

In the form of the apparatus designed by us and shown in the figure the cylinder A is exactly balanced by a sim cylinder B, both moving in similar tubes containing li at the same temperature. The conical ends of the cylin ensure their coaxial movement in the tube. A flexible Ny fibre connecting A and B passes over a light, almost frict less pulley. C and D are light weight carriers of ident shape and mass having holes into which riders of equal m m may be inserted.



Compensated moving cylinder viscometer

Before the cylinders are placed in the respective tubes, connected system is set in uniform motion in air by plac a suitable tiny mass X_1 on the appropriate side to compens any difference in the masses on either side and the sli friction. To reduce the friction at the pulley, the cylin have to be light. They may be either hollow cylinders solid ones of light material. We have used solid cylinders ebonite.

When n riders are placed say on the right side, the syst will move clockwise and a viscous drag will act on e

iameter of cylinders: 3·691 cm
Veight of rider: 0·8815 gm

Diameter of tubes: 3·772 cm
Circumference of pulley: 26·4 cm (*Distance moved in one rotation of the pulley, S*)
Time for one rotation of pulley T

Observations with compensated moving cylinder viscometer

). of ders	*Water*			*Mixture I*				*Mixture II*				*Mixture III*			
	Time T_1 (s) 1	2	*Mean*	*Time T_2 (s)* 1	2	*Mean*	$\frac{\eta_2}{\eta_1} = \frac{T_2}{T_1}$	*Time T_2 (s)* 1	2	*Mean*	$\frac{\eta_2}{\eta_1} = \frac{T_2}{T_1}$	*Time T_2 (s)* 1	2	*Mean*	$\frac{\eta_2}{\eta_1} = \frac{T_2}{T_1}$
3	243·8	244·4	244·2	300·2	300·6	300·4	1·230	341·7	342·7	342·2	1·402	364·6	365·6	365·1	1·487
4	180·0	180·5	180·25	221·7	222·3	220·0	1·231	252·5	252·9	252·7	1·402	258·4	259·2	258·8	1·490
5	140·0	140·2	140·1	171·8	172·4	172·1	1·228	196·2	197·0	196·6	1·404	208·7	208·9	208·8	1·491
						Mean	1·2297			*Mean*	1·4027			*Mean*	1·4893

Observations with Ostwald's viscometer

'o. of rvation	*Water*			*Mixture I*				*Mixture II*				*Mixture III*			
	Time t_1 (s)	*Mean*	*ρ_1 Density*	*Time t_2 (s)*	*Mean*	*ρ_2 Density*	$\frac{\eta_2}{\eta_1} = \frac{\rho_2 t_2}{\rho_1 t_1}$	*Time t_2 (s)*	*Mean*	*ρ_2 Density*	$\frac{\eta_2}{\eta_1} = \frac{\rho_2 t_2}{\rho_1 t_1}$	*Time t_2 (s)*	*Mean*	*ρ_2 Density*	$\frac{\eta_2}{\eta_1} = \frac{\rho_2 t_2}{\rho_1 t_1}$
1	55·4			63·25				72·2				76·2			
2	55·5	55·4	0·9974	63·2	63·25	1·0726	1·227	72·3	72·2	1·0734	1·403	76·25	76·25	1·0789	1·489
3	55·3			63·3				72·1				76·3			

inder. The motion becomes uniform when this drag is anced by the weight of the riders. From equation (3)

$$nmg = R \cdot \frac{\eta}{t} \tag{4}$$

This result may be used to compare the viscosities of two uids, using the same number of riders and noting the ne T for the pulley to turn once round. If η_1 and η_2 are viscosities of the two liquids and T_1 and T_2 are the pective times for a complete rotation of the pulley

$$\frac{\eta_1}{\eta_2} = \frac{T_1}{T_2} \tag{5}$$

Even if the friction of the pulley is not completely comnsated by the mass X_1 initially placed, equation (5) is still lid.

The time of revolution is correctly noted by attaching a cular paper scale to the rim of the pulley and observing movement of the scale divisions through a telescope. servations of time are taken for various numbers of lers. The experiment may be repeated with the system oving in the reverse direction using another compensating ass X_2. Nylon fibre was used to connect the masses cause it is strong and does not get wetted by ordinary uids.

Viscosities of mixtures of glycerine and water of different ncentrations have been compared with that of water ing this method. It will be seen from the table that the mpensating moving cylinder viscometer yields values agreeing well with those obtained from an Ostwald's viscometer, testifying to the accuracy obtainable.

The constant R of equation (4) may be determined using a standard liquid of known viscosity and the viscosity of any other liquid can be calculated using this value of R. Advantages over the falling cylinder viscometer are:

(1) In this compensated moving cylinder viscometer the velocity of steady motion can be easily adjusted to any desired value by choosing the proper number of riders instead of altering the weight of the cylinders. The instrument can hence be used for liquids over a wide range of viscosities.

(2) The densities of the liquid and cylinder have not to be determined.

(3) The apparatus is useful for all kinds of liquids transparent or opaque as the actual movement of the cylinder has not to be observed. The rotation of the pulley gives the necessary information.

(4) The observations of time T may be repeated any number of times for the same number of riders while such repetition is difficult in the original falling cylinder form of the viscometer.

REFERENCES

(1) Lawaczeck. *Z. Verein. Dtsch. Ingen.* [*VDI*], **63**, p. 677 (1919).

(2) Bridgman. *Proc. Amer. Acad. Arts Sci.*, **61**, p. 57 (1926).

(3) Dow. *Physics*, **6**, p. 71 (1935).

(4) Awbery and Griffiths. *Proc. Phys. Soc.* [*London*], **48**, p. 372 (1936).

A double d.c. bridge circuit for precision measurements with load cells*

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[*Paper received* 12 *August*, 1957]

By arranging the strain gauges on a load cell as a closed bridge which is wired in parallel with a similar reference bridge in the measuring instrument, a very sensitive and accurate manually balanced null deflexion method of measuring the output of a load cell can be achieved at low cost. This method is also suggested as an alternative to the present d.c. methods used for load cell measurement in the calibration of testing machines.

The prototype bridge has a discrimination of one part in 10000. A practical difficulty when used with load cells greater than 50 tons capacity is to calibrate against a standard of sufficiently high accuracy.

INTRODUCTION

A.C.-energized load cell circuits have been developed for high accuracy in static measurements, usually for manually-balanced instruments, but they tend to be fairly complicated electronically and rather expensive. The d.c. circuit offers an inherently simpler arrangement.

The main and compensating gauges are usually affixed to the load cell, and wired as a closed bridge to give the best temperature compensation and to minimize errors due to leads, plugs and switching and to obtain added sensitivity from the Poisson ratio effect. The gauges are energized by a d.c. source across two apices of the bridge and the potential developed across the other apices can be measured in various ways but most accurately, though less simply, by means of a d.c. potentiometer. In the latter method the voltage applied to the cell must be accurately known, and preferably checked before each reading, whilst the potentiometer itself must be standardized against a Weston cell.

The double d.c. bridge described herein enables load cell measurements to be made simply, accurately, and virtually independent of variations in applied voltage.

THE DOUBLE D.C. BRIDGE

The double d.c. bridge (see Fig. 1) is essentially two Wheatstone bridges in parallel, energized from a common source. As the output of the load cell is in parallel with the measuring bridge and galvanometer, fractional changes of resistance in the arms of the load-cell bridge can be balanced by means of twin-ganged slide wires in the measuring bridge so that a null deflexion is obtained on the galvanome The slide-wire movement is an almost linear function of out-of-balance of the load cell. By making the slide w as helices, a discrimination commensurate with the accur required can be achieved. In this case the accuracy ai at was 0·1% of scale reading.

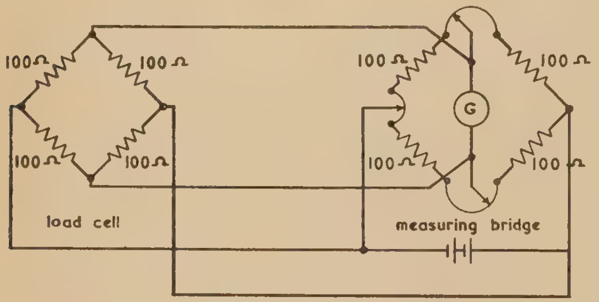

Fig. 1. Double d.c. bridge circuit

The arrangement has the following advantages:

(i) It is a comparative method, involving no abso measurements of voltage or current.

(ii) Being a bridge method of measurement, it is indep dent of variation in applied voltage, except in so far as la fluctuations (unlikely in practice) could cause second heating or other effects.

(iii) Any variation in the resistance of leads, plugs sockets has a minimum effect on the accuracy of the ins ment, and no additional leads are required to achieve this

(iv) Because the circuit is symmetrical and because bridges on the load cell and in the measuring instrument each closed bridges, a high degree of temperature co pensation is achieved whatever the physical distance betwe and the temperature of, load cell and instrument might with consequent minimizing of drift due to temperat change.

(v) The load cell can be used in conjunction with an self-balancing measuring instrument, if so desired, for accurate work.

(vi) No dummy gauges or potential divider have to used in the load cell.

(vii) Only one battery is required.

The present d.c. methods of measuring resistance cha in load cells or other transducers each has some of above advantages, but none has all of them.

DESCRIPTION OF THE MEASURING BRIDGE

It was decided to make the twin ganged slide wires ea 200 in. long. They are arranged as helical windings of turns each on a $6\frac{3}{8}$ in. diameter former. The 6 in. diame dial of 100 divisions makes ten revolutions, and, as ea division is easily read to one-tenth by means of the verni the discrimination is one part in 10000.

The construction of the instrument is best understood reference to the circuit diagram in Fig. 2 and illustrati (Fig. 3).

The slide wires consist of 20 s.w.g. 40% silver-palladiu wire, wound under constant tension on a marble former helices of 0·2 in. pitch. The wipers are formed from 6 alloy (by Johnson, Matthey and Co. Ltd.) (copper–silve ld) strip 0·01 in. thick and ¼ in. wide. The screw which verses the wipers axially along the marble former is a o-start metric thread of 5 mm (0·197 in.) lead, which, in njunction with the 0·2 in. pitch, causes the wipers to ve slightly across the slide wires—the usual method of oiding a groove in the wiper. Geared from the main indle is a small dial of ten divisions to count the revolutions the main spindle.

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* The apparatus described in this Technical Note is the subject of Provisional Specification No. 32527/56, filed 25 October, 1956—"Improvements in or relating to Apparatus and Method for Measuring Changes in Electrical Resistance."

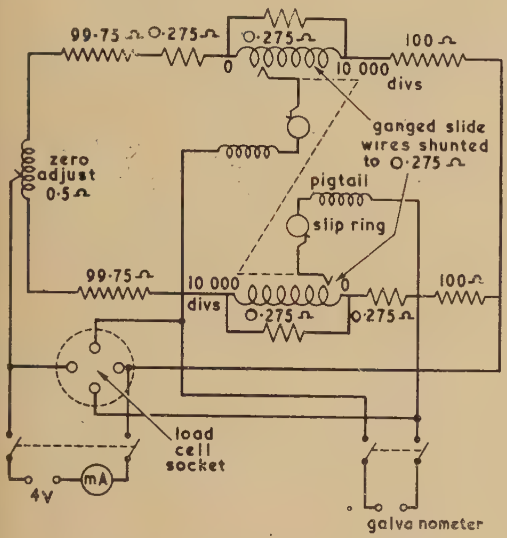

Fig. 2. Circuit of measuring bridge

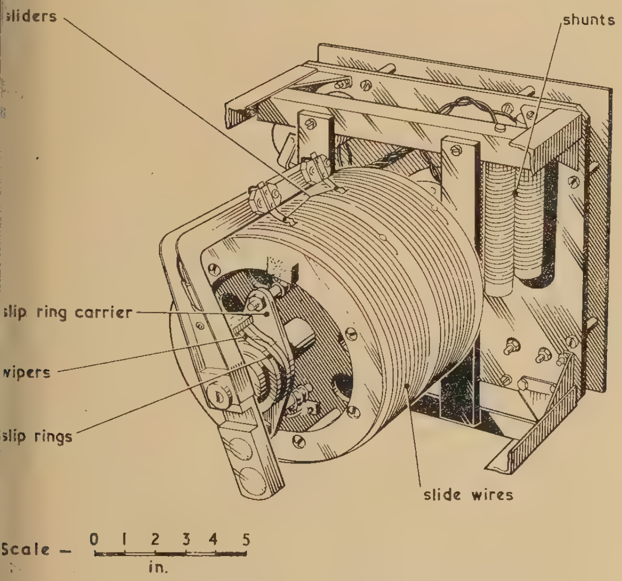

Fig. 3. Rear view of measuring bridge

The slide-wire wipers are wired to similar wipers running n rhodium-plated slip rings mounted on the Tufnol bushes f a slip-ring carrier. These slip rings are prevented from tating and slide axially with the wiper arm spindle. Lead ires from the slip rings are wound helically on the slip-ring rrier rods to accommodate the axial movement.

A helical zero-adjusting potentiometer of 0·5 Ω in one apex f the instrument bridge arms allows for initial out-of-balance individual load cells.

Behind the main panel are mounted slide-wire shunts and ur-arm standards of 100 and 99·75 Ω, which, with the 0·5 Ω zero adjustment, match the 100 Ω arms in the load cell bridge.

On the front panel are mounted:

(*a*) the fast and slow-motion concentric knobs driving the slide-wire wipers;

(*b*) a window through which the slide-wire dial scale and vernier can be read;

(*c*) the zero-adjusting knob;

(*d*) the galvanometer terminals and switch;

(*e*) the battery terminals and switch;

(*f*) a milliammeter to indicate battery current;

(*g*) a Mark IV, six-pin plug (by Plessey Co. Ltd.), for load-cell connexion.

In this particular application, 4 V are applied to the complete circuit, giving a total current drain of 80 mA. One hundred ohm bridge arms were chosen for the load cells to enable them to be used with a commercial a.c. self-balancing recorder.

CALIBRATION OF BRIDGE

An assessment of the repeatability of the measuring bridge was made by injecting signals from a "dummy load cell" consisting of a precision slide wire Wheatstone bridge (by Cambridge Instrument Co. Ltd.), with a high stability 100 Ω standard across its X terminals. In this way the Cambridge instrument formed a closed bridge, similar to that on a load cell, the out-of-balance of which could be changed by varying one arm in 0·1 Ω increments with a certified accuracy of 0·025%. The repeatability of the 0·1 Ω steps could be expected to be of higher accuracy than this, relying solely on the switching variations in the decade. In this way ten accurate "loads" could be applied. Tests carried out over a period of six months showed that the maximum variation between the readings for any one "load" did not exceed 0·21%. No temperature corrections were applied.

The bridge was also connected to a 250-ton load cell designed and manufactured by the Military Engineering Experimental Establishment, and calibrated at the National Physical Laboratory. The calibrations up to 50 tons were performed in the 50-ton dead-weight machine which has an accuracy of one part in 25 000. The variations in readings at 50 tons were better than ±0·1% of the 50-ton scale reading which is near the limitation of discrimination of the slide wire scale reading. The maximum zero drift was −0·1%.

For loads above 50 tons the calibration was carried out by comparison with a N.P.L. load gauge of 250 tons capacity and a certified accuracy of ±¼% of scale reading. However, the N.P.L. load gauge is expected to have a repeatability better than ±0·1% in one "set up."

Assuming, however, the N.P.L. equipment to have no error, and all discrepancies to be in the double d.c. bridge and load cell, then the maximum deviation in reading from the average of six runs was one part in 830 (or 0·3 ton) at 250 tons. The worst deviation occurred at 100 tons, being one part in 630 (0·16 ton).

ACKNOWLEDGEMENT

The author is indebted to Mr. E. Longbottom for his support and valuable comments.

Derivative mass spectrometry

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[*Paper received* 24 *December*, 1957]

Double differentiation of the ion beam in a mass spectrometer is shown to have the same effect on peak shape as reduction to zero width of the inlet and exit slits. When this differentiation is performed by modulation of the accelerating voltage, increase of the modulating amplitude results in effective control of the width of both inlet and exit slits making the spectrometer more versatile since its sensitivity and resolving power are easily controlled. Differentiation by an odd number of times enables the centre of a singlet peak to be located with greater speed and accuracy, thus improving the mass measurements made with the spectrometer.

1. INTRODUCTION

Much of the information obtained in a research laboratory is in the form of spectra which generally consist of series of peaks of differing heights and separations, often with some overlapping of adjacent peaks. Any instrument which records such spectra, and by so doing measures a function of a single variable which is under the control of the experimenter can, in principle, be modified to measure any derivative of the function with respect to the same variable. This can be shown to have the advantage that the heights and positions of overlapping peaks can be determined more easily and with greater accuracy. Indeed, the effective resolving power of a spectrometer can generally be increased by the recording of derivatives.

Plotting the first derivative of the required function is common in nuclear magnetic resonance and electron paramagnetic resonance spectroscopy while second derivatives of infra-red absorption spectra have also been obtained.(1,2) In the determination of ionization potentials proposals for the direct measurement of first derivatives of ionization efficiency curves were made many years ago (see Ref. 3, p. 235, for review) and more recently Morrison(4) has extended this technique to obtain second derivatives. Here we shall describe briefly the technique which we have applied to mass spectrometry and discuss the benefits achieved.

The additional information which can be obtained by the study of a derivative of a spectrum depends on the shape of the peaks in the spectrum. In infra-red absorption spectrometry, for example, all peaks in a spectrum are not of the same shape and the amount of information obtainable by differentiation will vary from sample to sample. In mass spectrometry, on the other hand, all singlet peaks are of nearly the same shape. It is thus possible to predict, knowing this shape, the improvements to be expected from plotting derivative spectra, and to consider the ideal peak shape, and how this may be approached. Differentiation is a distributive operation so that quantitative analysis can be performed just as well on derivatives as on conventional peaks. Further, if the original peak has a plane of symmetry, so will all its even derivatives, while its odd derivatives will have a centre of inversion.

2. METHODS OF OBTAINING DERIVATIVES

The output of a spectrometer may be differentiated with respect to time by electronic means or by modulation of the independent variable.(3,4) The first of these methods has the disadvantage that the strength of the resulting signal depends on the scanning speed, and this may not be capable of variation over wide limits nor will the detection system of the spectrometer be capable of accepting a wide range of signal frequencies without an increase in the background noi Furthermore, the equipment necessary becomes mc complicated the higher the derivative required. The seco method is free from these disadvantages and since the streng of the derivative signal is independent of time, the meth can be combined with slow scanning of the peak with cc sequent improvement in signal to noise ratio. The metho which can be applied to any spectrometer in which t independent variable can be controlled, has been used in o mass spectrometer in the following way.

Let the mass peak, expressed as a function of the acceler ing voltage V, in a single-focusing sector type mass spec meter be $f(V)$; then by Taylor's Theorem,

$$(V + A\sin\omega t) = \left[f(V) + \frac{A^2}{4}f''(V) + \ldots\right] + $$

$$+ A\sin\omega t\left[f'(V) + \frac{A^2}{8}f'''(V) + \ldots\right] -$$

$$-\frac{A^2\cos 2\omega t}{4}\left[f''(V) + \frac{A^2}{12}f^{\text{iv}}(V) + \ldots\right] \quad ($$

Hence if $A^2 \ll \dfrac{f^n(V)}{f^{n+2}(V)}$,

$$f(V + A\sin\omega t) \simeq f(V) + A\sin\omega t f'(V) -$$

$$-\frac{A^2}{4}\cos 2\omega t f''(V) + \ldots \quad ($$

Therefore modulation of the accelerating voltage V with small amplitude at a frequency $\omega/2\pi$ generates harmonics this frequency, each of amplitude proportional to the corr sponding derivative of $f(V)$ with respect to V. It is on necessary to select the appropriate harmonic to measure a desired derivative. Some distortion is inevitable with finite amplitude of modulation and it is shown below th the effect is analogous to that caused by the finite slit widt in conventional machines.

The experimental arrangement used for the above metho of differentiation, simply involves the replacement of th conventional mass spectrometer d.c. amplifier by a narro band a.c. amplifier, while a tuneable oscillator provides th modulation voltage which is superimposed on the io accelerating voltage. Our instrument uses a "cascode tuned amplifier, the parallel filters being replaceable, so th it tunes at either 75 c/s or 190 c/s. An audio frequency sign generator working down to 20 c/s provides the modulati voltage. First derivatives are obtained when the sign generator is set to the tuning frequency of the amplifie *n*th derivatives are obtained by reducing the oscillat frequency to $1/n$ of this frequency. The first derivative of mass peak consists of a positive lobe followed by a negati e, but since the arrangement used is not phase sensitive, th these lobes appear on the same side of the base-line and et in a V-shaped valley extending to the base-line. This m of peak is in fact convenient for recording purposes ce then the base-line can be at the side of the chart, enabling full width of chart to be used for recording each lobe. ase sensitive detection if required would be a simple dition. Two major advantages arise from the differentia- n of a mass spectrum. It provides an increase in the ecision of mass measurement and a simple control over the solution of the instrument.

Mass measurement is of considerable importance in the plication of mass spectrometry to the identification of ganic compounds, since the atomic composition of an ion n be found simply by a sufficiently accurate measurement its mass. The usual method of mass measurement used th our sector-type mass spectrometer, is to measure the celerating voltages at which the unknown, as well as a own peak appear, at constant magnetic field. The main jection to such a measurement lies in the fact that the sition of the maximum of each peak must be determined, d this is difficult since the maximum corresponds to zero pe of the peak. The rate of change of slope is, however, rge at the maximum provided that the exit slit is not too de. Thus if the first derivative of each peak is plotted, the sition at which this curve passes through zero must be termined and since the signal is zero the measurements n be carried out at maximum sensitivity. Measurements hich we have carried out show that the reproducibility and eed of mass determinations are both increased in odd rivative spectra.

3. THEORETICAL

The control of the resolving power arises because a new rameter is at the operator's disposal. This is the amplitude modulation A. Equation (1) shows that the signal at all rmonics of the modulation frequency depends on A so at first of all A is a sensitivity control. However, as A creases, the higher order terms neglected in (2) become creasingly important, constituting effectively a distortion om the derivative shapes.

If an axis x' is taken perpendicular to the ion beam tra- ctory and to the inlet slit edges, then for a given ionic mass , and suitable accelerating voltage V, an image x of this is will be formed perpendicular to the exit slit edges and planar with x'. The positions of the exit slit edges x_{e2} on the axis x are linear functions of $V^{\frac{1}{2}}$, but if we nsider only small changes in V then $\frac{dx_{e1}}{dV} = \frac{dx_{e2}}{dV} = p$ (say) constant to a sufficient degree of approximation. The ion rrent through the exit slit $f(V)$ is the result of scanning the n distribution $F(x)$ across the exit slit.

$$f(V) = \int_{x_{e2}}^{x_{e1}} F(x)dx \tag{3}$$

nly for a very narrow slit does $f(V)$ become proportional $F(x)$. With modulation the signal amplitude at the odulation frequency, given by (1) becomes

$$\begin{aligned} ApF(x_{e1}) + \frac{A^3p^3F''}{8}(x_{e1})\ldots\Big] - \\ - \left[ApF(x_{e2}) + \frac{A^3p^3F''}{8}(x_{e2})\ldots\right] \end{aligned}$$

ving a positive lobe due to the exit slit edge at x_{e1} and a gative lobe due to the slit edge at x_{e2}. The lobes will overlap if the slit is not wider than $F(x)$. The second lobe could be removed in principle by doing away with the second slit edge. For small amplitude of modulation, the lobe due to the first slit edge approximates to $ApF(x_{e1})$, and this is approximately equal to the ion beam which would be collected by a narrow slit of width Ap with conventional detection. Hence for detection at the modulation frequency, the modulation amplitude may be regarded as a controllable virtual exit slit. The price paid for this facility is the duplication of the spectrum. Provided the exit slit is wide enough, then except at masses high enough for overlapping of adjacent mass peaks to occur, this duplication is relatively unimportant, and could in fact be used to facilitate automatic range changing, the first lobe providing the information to allow of the pre-selection of the appropriate range on which the second lobe could be recorded.

In mass spectrometry there is competition between the claims of resolution and sensitivity, and slit widths (which are not readily adjustable) are made of such a size as to give a compromise between these two factors. The virtual slit whose width depends only on a voltage makes possible a considerable increase in the versatility of the instrument and enables higher resolution or higher sensitivity than the compromise values to be achieved. This has been widely recognized and has resulted in the development of electrostatic lenses(5) for the electrical control of effective exit slit width. The method described here provides virtual slits without the necessity for additional electrodes, and also offers the possibility in high resolution mass spectrometry of effectively narrower slits than can readily be obtained in conventional operation.

Consider now the signal obtained at twice the modulation frequency. Suppose that an infinitely thin inlet slit at a point x_1' forms an image at the exit slit of the form $\phi(x - x_1)$ and that the illumination of the inlet slit region may be expressed by $I(x')$, then the ion distribution $F(x)$ along the axis x is given by

$$F(x) = \int_{x_{i2}}^{x_{i1}} I(x_1)\phi(x - x_1)dx_1$$

where x_{i1}' and x_{i2}' delineate the inlet slit edges on the x' axis and x_{i1}, x_{i2} on the corresponding points on the x axis. Hence from (3)

$$f(V) = \int_{x_{e2}}^{x_{e1}} dx \int_{x_{i2}}^{x_{i1}} I(x_1)\phi(x - x_1)dx_1 \tag{4}$$

assuming for simplicity that the magnification of the magnetic lens is unity. Differentiating (4) twice with respect to V and regarding x_{e1} and x_{e2} as linear functions of V, we have

$$\begin{aligned} f''(V) = p^2[I(x_{i2})\phi(x_{e1} - x_{i2}) - I(x_{i2})\phi(x_{e2} - x_{i2}) - \\ - I(x_{i1})\phi(x_{e1} - x_{i1}) + I(x_{i1})\phi(x_{e2} - x_{i1})] + \\ + p_2\int_{x_{i2}}^{x_{i1}} I'(x_1)[\phi(x_{e1} - x_1) - \phi(x_{e2} - x_1)]dx_1 \end{aligned} \tag{5}$$

and since the amplitude of the signal at angular frequency 2ω is $\frac{A^2}{4}f''(V)$ for small values of A, equation (5) represents to a first approximation the form of this observed signal. In the case of uniform illumination of the inlet slit, equation (5) reduces to the four similar lobes $\phi(x_{e1} - x_{i2})$, etc., centred at values of V corresponding to $x_{e1} = x_{i2}$, etc. Whether the lobes overlap to any significant extent depends simply on the width of the inlet and exit slits relative to the width of the function ϕ. The separation of the lobes $-\phi(x_{e1} - x_{i1})$ and $\phi(x_{e1} - x_{i2})$ is proportional to the inlet slit width; the separation of $-\phi(x_{e1} - x_{i1})$ and $\phi(x_{e2} - x_{i1})$ is proportional to the exit slit width and the separation of $\phi(x_{e1} - x_{i2})$ and $\phi(x_{e2} - x_{i1})$ is proportional to the difference between the slit widths. By suitable choice of slit widths, the lobes may be separated, so that a quadrupled picture is obtained and each lobe is just the peak that would be observed with conventional operation using infinitely thin inlet and exit slits and represents the maximum resolution of which the electromagnetic lens system is capable. Of course A must be small or the higher order terms broaden the lobes. It thus appears that the effect of reducing the amplitude of modulation in the second derivative is equivalent to reducing both inlet and exit slits.

The contribution to the signal due to the non-uniform illumination of the inlet slit is represented by the second term in equation (5). In order to obtain the order of magnitude of this contribution, the function ϕ may be approximated by a rectangle $\phi(O)$ in height and of width w. The second term of equation (5) then become approximately $p^2 w\phi(O)(I'(x_{e1}) - I'(x_{e2})$ and the condition that this should be small compared with the first term is $wI' \ll I$ or that fractional changes in I should be small over distances equal to the width of the function ϕ.

4. RESULTS

Examples of signals which have been obtained are shown in Figs. 1 to 4. Fig. 1 shows the first derivative of the doublet peak $OH^+ - NH_3^+$, successive curves showing the effect of reduction of modulating voltage. The inlet and exit slits of the mass spectrometer were both of width 0·01 in., the radius of the instrument being 6 in. The sensitivity of the recorder has been adjusted for each curve. It can be seen that each curve gives a duplicated picture of the doublet, the resolving power increasing as the amplitude of modulation is decreased, corresponding to closing the virtual exit slit. Fig. 2 shows the pattern with an adjacent singlet peak at mass 16 for comparison. The effect of the superposition the doublet patterns is clearly seen in Fig. 3 which cons of a second derivative of the doublet with the exit slit wi set so that the overlapping of lobes of opposite phase is slig A singlet peak under the same conditions is also shown. is clear from Fig. 3 that the outermost pair of peaks unaffected by overlap and since each is due to one compon of the doublet, their relative heights may be used to determ the relative abundances of the ion species. The origi peak may not be perfectly symmetrical and since this asy metry will be accentuated by double differentiation, a c rection factor determined from the shape of a singlet p must be applied to the abundance measurements.

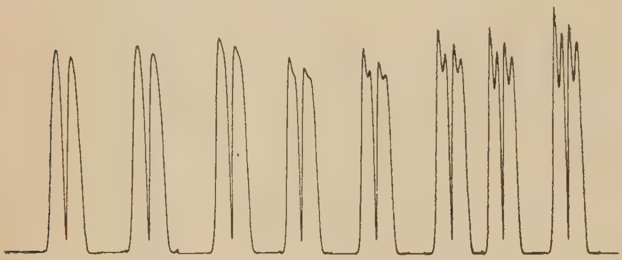

Fig. 1. First derivatives of the doublet $OH^+ - NH_3^+$; modulation amplitude decreasing from left to right. Sensitivity of detector adjusted for each curve

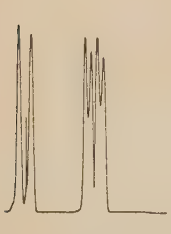

Fig. 2. Singlet peak NH_2^+ and doublet $OH^+ - NH_3^+$

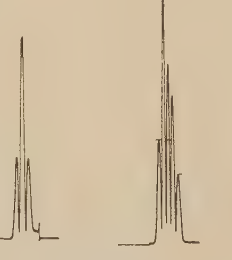

Fig. 3. Second derivatives of singlet NH_2^+ and doublet $OH^+ - NH_3^+$

5. DISCUSSION

Overlapping of the various lobes in a derivative p hinders the interpretation and is best avoided by the use wide slits. In our instrument it is unfortunately not possi to vary the width of the inlet slit, and the pictures obtai are, therefore, more complicated than they would other be. However, Fig. 4 was obtained in an attempt to det the doublet $C_6H_{12}^+$, $C_5H_8O^+$ for which $\frac{M}{\Delta M} \doteq 2325$. Cl evidence of doublet structure is seen in one of the peaks Fig. 4 while the other pattern was obtained simply by rem ing the $C_5H_8O^+$ ion and adjusting the sensitivity for ease comparison.

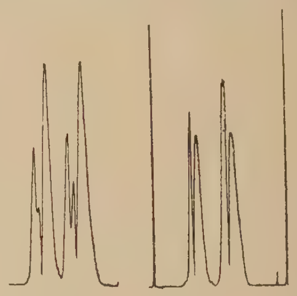

Fig. 4. Second derivative of the doublet $C_5H_8^+O - C_6H_{12}^+$ and the singlet $C_6H_{16}^+$ with wide exit slit

The advantages gained by differentiating the mass spectru have been obtained by exploiting the discontinuities in t ion distribution introduced by the slit edges. Higher deri tives than the second will yield the successive derivatives $\phi(V)$, but since this shows no discontinuities, the main eff will merely be further to complicate the picture obtaine $\phi(V)$ is compounded of the energy spread in the ion bea the aberrations of the magnetic lens system, scattering a space-charge defocusing effects. The inherent resolvi power of a mass spectrometer increases as these effects a reduced. Removal of the effect of energy spread in doub focusing machines increases the inherent resolving pow while the use of wide inlet and exit slits enables the sar machine to be used whenever required with high sensitiv and low resolving power.

REFERENCES

(1) Giese, A. T., and French, C. S. *Appl. Spectrosc.*, p. 78 (1955).
(2) Collier, G. L., and Singleton, F. *J. Appl. Chem.*, p. 495 (1956).
(3) Barnard, G. P. *Modern Mass Spectrometry* (Londo The Institute of Physics, 1953).
(4) Morrison, J. D. *J. Chem. Phys.*, **22**, p. 1219 (1954).
(5) Craig, R. D. *Applied Mass Spectrometry*, p. 2 (London: The Institute of Petroleum, 1954).

An electronic feedback seismograph

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The seismograph described has a nearly uniform response to ground oscillations whose periods lie between 1·5 s and 12 s, which is the range of particular interest for research on microseisms generated by sea waves. The seismograph consists of a 1 s pendulum which measures ground acceleration over the range of frequencies of interest, and an electronic circuit performing double integration to give a signal proportional to ground displacement. The 1 s pendulum has negative feedback which allows simple damping arrangements and easy absolute calibration, as well as improving stability and linearity. A horizontal-component instrument has been built, but the principle should be equally applicable to measuring the vertical component.

ven when there are no earthquakes being recorded, a nsitive seismograph shows a continual background of small rth movements, which are a nuisance to an earthquake ismologist since they limit the useful sensitivity of the ismograph. Investigation has shown that in at least some rts of the world most of this background signal is generated y sea waves (Darbyshire⁽¹⁾): conditions must be such that ave trains of the same period are travelling in opposite rections, and this can happen in a fast moving storm or hen waves are reflected from a coast. U.S. scientists have een using this effect for some time to help detect hurricanes eveloping in the Atlantic (Donn and Blaik⁽²⁾). Darbyhire⁽³⁾ has recently been developing a system which promises o be more satisfactory. The problem of detecting tropical orms forming in an area where there is little or no shipping also important in the Indian Ocean.

Benioff⁽⁴⁾ has reviewed the various types of earthquake eismographs known to be in use at that time. Though some f these can be used to measure microseisms, it was felt that more satisfactory instrument could be designed if this pplication were the main consideration. The seismograph escribed here is robust and mechanically simple, gives ufficient output to work any of the usual types of robust ecorder, has a frequency response "tailored" to the application, is relatively easy to calibrate, and has other minor dvantages. It is hoped to make the final design such that he instrument can simply be buried in the ground, avoiding he necessity of vaults or cellars and eliminating troubles rom draughts or rapid temperature changes.

The seismograph is typically operated with a magnification atio of 5000.

PRINCIPLE OF OPERATION

This is shown in Fig. 1. A pendulum with a 1·6 s natural period has the displacement of its bob relative to the base measured by a transducer which gives a 1000 c/s signal balanced to zero output in the mean position. This signal is mplified and rectified taking account of the phase, giving a d.c. voltage proportional to the bob displacement relative to he base. This voltage is fed through a resistance R to a coil ixed to the bob and with one of its vertical sides in the field of a permanent magnet fixed to the base. The sense of connexion is such that the force produced by this coil reduces he deflexion, so that the stiffness of the pendulum is increased and the period reduced to 1 s. Optimum damping is achieved by shunting the feedback resistor with a suitable capacitor C, which passes a current proportional to the rate of change of voltage and thus produces a force proportional to bob velocity.

For ground oscillations with periods greater than about ·5 s, the output voltage of the rectifier is proportional to one horizontal component of ground acceleration. This voltage is passed through a long time-constant capacitance-resistance coupling to remove any steady component (due to tilt of the instrument, for example), and is then integrated twice and amplified to give an output proportional to ground displacement.

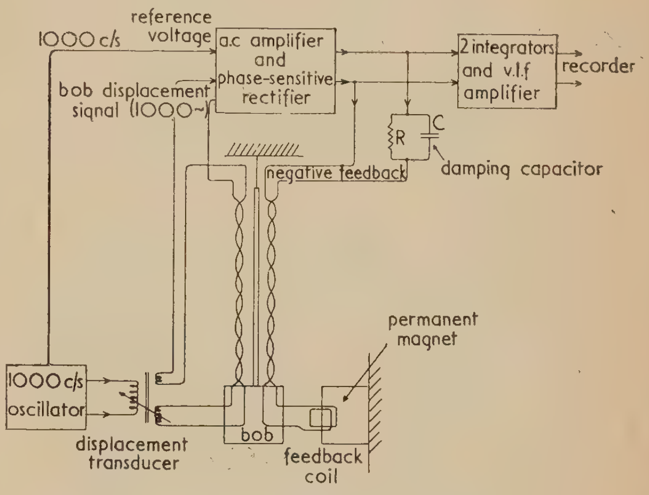

Fig. 1. The principle of the instrument

It is advantageous to start with a pendulum whose natural period is as long as possible, since this improves the ratio of signal to noise generated in the transducer and electrical system. If, as in the present case, this period lies in the range of interest, negative feedback is required to shorten the period. However, the negative feedback also has the other advantages usually associated with it: it improves the linearity of the amplifier and detector and stabilizes the sensitivity. In the present system it also provides convenient methods of damping and of absolute calibration (see below).

THE MEASURING PENDULUM

Photographs of the pendulum and of the bob are shown in Figs. 2 and 3. The pendulum is hung in a rack designed for taking standard 19 in. electronic panels, which is clamped to a rigid steel base-plate mounted on three levelling screws. The suspension is a piece of piano wire clamped into a ½ in. diameter aluminium rod and capable of being rotated for lining up the coils. The four leads from the coils are carried past the piano wire by spirals of 42 s.w.g. enamelled copper wire. In the prototype the bob consists of a cylinder of aluminium, but stray field from the transducer stator produces a just appreciable force on the bob so that future instruments will have bobs made of an insulating material.

This prototype instrument, which was made largely from parts of other instruments put together by the author (who is no mechanic!), does not represent the most elegant arrangement possible, but it has proved the principle and a properly engineered model is now being made.

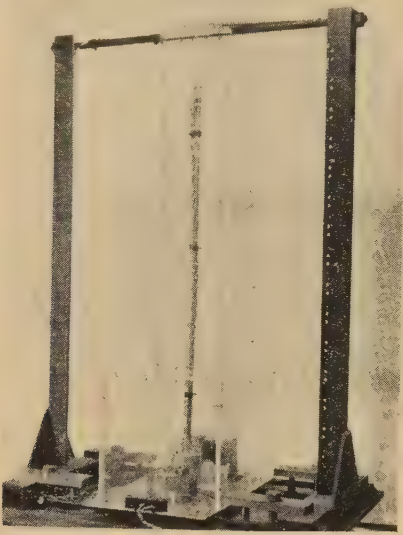

Fig. 2. Photograph of the prototype instrument

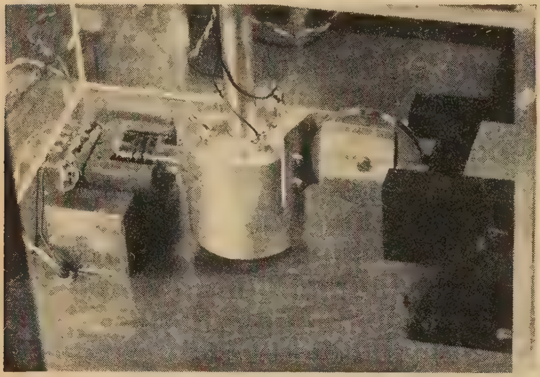

Fig. 3. Details of the bob and measuring and feedback arrangements. The bob is approximately 5 cm in diameter

THE DISPLACEMENT TRANSDUCER

The displacement transducer used is the variable-coupling transformer type described by Tucker.(5) Its principle is shown in Fig. 4. A stack of *E*-type transformer laminations has a coil wound round the base of the centre limb and supplied with 1000 c/s alternating current. A secondary coil attached to the pendulum bob moves over the centre limb and picks up a voltage proportional to the number of lines of force threading it, which varies linearly with displacement. The voltage picked up in the mean position is balanced against the voltage of a fixed secondary coil, so that the final output is proportional to displacement from the mean position with a phase reversal between positive and negative displacements.

The electrical balance is good since the two voltages are induced by more or less the same field, and stable since it depends almost entirely on relative mechanical positions. A small residual quadrature voltage (about 10^{-3} of the volt of one coil) is balanced by an adjustable quadrature volt generated across a 2 μF capacitor. An even smaller th harmonic residual is reduced adequately by using a tu output transformer in the a.c. amplifier. With the arran ment used in this seismograph, the transducer gives appro mately 0·5 mV/μ from an impedance of about 100 Ω.

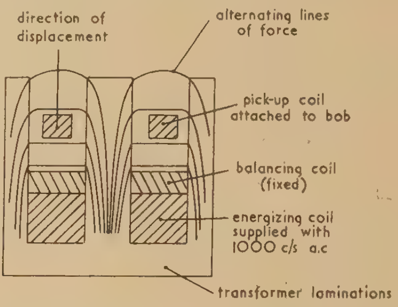
direction of displacement
alternating lines of force
pick-up coil attached to bob
balancing coil (fixed)
energizing coil supplied with 1000 c/s a.c
transformer laminations

Fig. 4. The principle of the displacement transducer

The advantage of this transducer for the present applicati lies mainly in the negligible reaction force on the moving co but it is also simple, has comparatively large clearances, a no close tolerances.

THE INTEGRATORS

The basic electronic integrator is extremely simple an shown in Fig. 5(*a*). If Q is the charge on the capacit $V_0 = Q/C$ and $i = dQ/dt = C(dV_0/dt)$. Also $i = (E_1 - V_0)/$ So

$$(E_1 - V_0)/R = C(dV_0/dt)$$

and

$$V_0 = (1/RC)\int^t (E_1 - V_0)dt$$

If V_0 is kept small compared with E_1,

$$V_0 \simeq (1/RC)\int^t E_1 dt$$

The error if V_0 is not kept small is important for optimu design, and can fortunately be represented by the simp transformation shown in Fig. 5(*b*) (Tucker(6)), where appears as the voltage drop across a *C.R.* coupling. Thu the criterion for optimum design is that the value of t product *RC* (the "time-constant") is just sufficiently large f a *C.R.* coupling with the same values to pass the lowe frequency in the signal without serious attenuation. In t present circuits $RC \simeq 4$ s. It is advantageous to make t time-constant no greater than is necessary, partly because t sensitivity of the integrator is inversely proportional to and partly because the greater it is, the greater is the relati response to troublesome long-period oscillations.

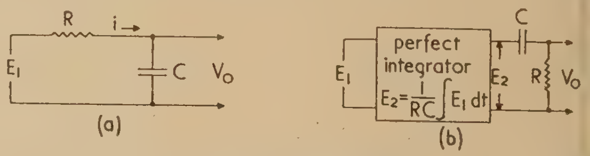

Fig. 5. (*a*) Basic electronic integrator circuit; and (*b*) its equivalent

When very long time-constants are required, the effecti value of C may be increased by a feedback arrangement, b this is not necessary in the present application.

THE ELECTRONIC SYSTEM

The electronic circuit is shown in Fig. 6. V_1 is a simple 00 c/s oscillator using the primary of the transducer as inductance of a tuned circuit. The output of the transducer amplified in V_2 and passed through a tuned transformer to phase-sensitive rectifier V_3. The output of the rectifier is ssed to the feedback coil through a resistance and capaci- nce and a test switch (see below). A microammeter in ies with the feedback resistor measures tilt of the pendulum, ich is adjusted by the levelling screws to give a zero reading. The output of the rectifier, which has a sensitivity of 00 V cm^{-1} s^2, also passes to the first integrator and the anti- ift coupling followed by a balanced d.c. amplifier V_4. The utput of V_4 feeds the second integrators followed by a cond d.c. amplifier V_5 and a cathode-follower output age V_6. The output impedance is approximately 1000 Ω, d the sensitivity of the instrument is adjusted by connecting resistor in series with the recorder. The power supplies are rived from a conventional unit supplied from the a.c. ains through a stabilizing transformer.

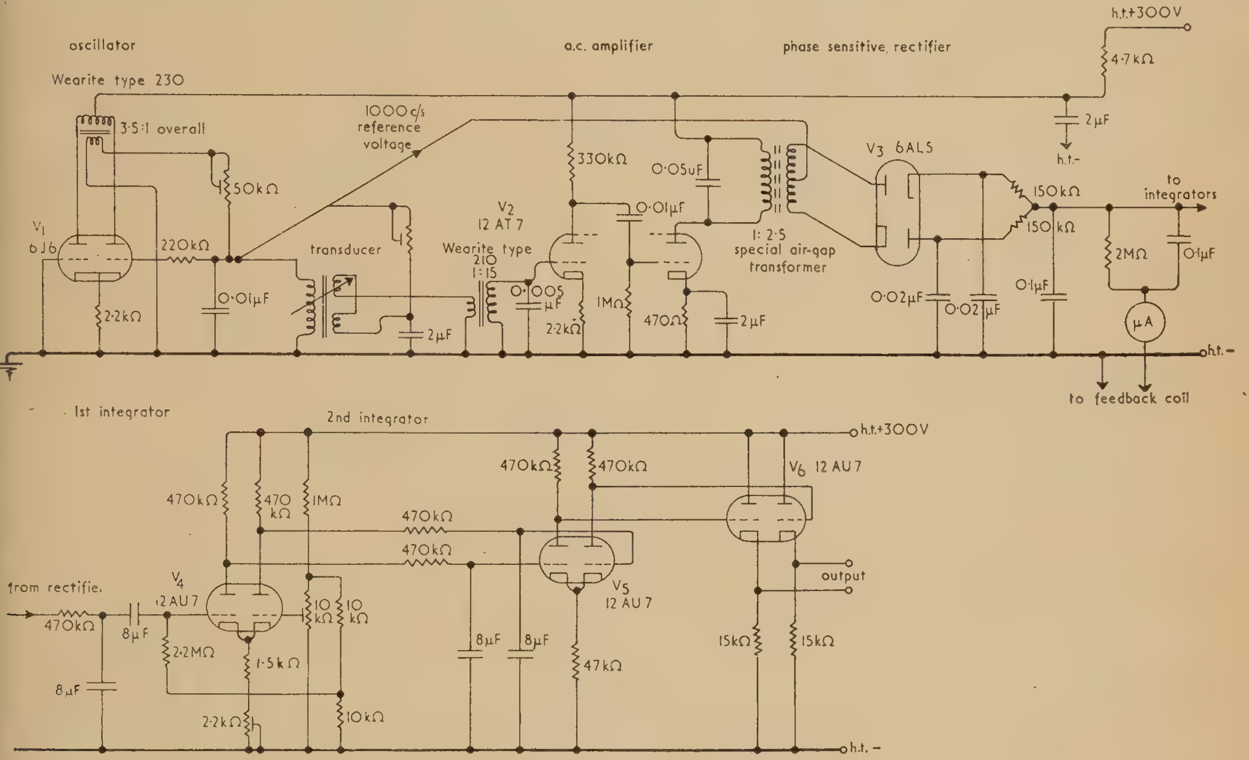
oscillator
Wearite type 230
3·5:1 overall
1000 c/s reference voltage
50kΩ
V1 6J6
220kΩ
2·2kΩ
0·01μF
transducer
2μF
V2 12 AT 7
Wearite type 210 1:15
0·005 μF
2·2kΩ
a.c. amplifier
330kΩ
0·01μF
0·05uF
1MΩ
470Ω
2μF
1: 2·5 special air-gap transformer
phase sensitive rectifier
V3 6AL5
h.t.+300V
4·7kΩ
2μF
h.t.-
150kΩ
150kΩ
to integrators
2MΩ
0·1μF
0·02μF
0·02μF
0·1μF
μA
h.t.-
to feedback coil
1st integrator
2nd integrator
h.t.+300V
470kΩ
470kΩ
1MΩ
470kΩ
470kΩ
470kΩ
470kΩ
V6 12 AU7
from rectifie.
470kΩ
8μF
V4 12AU7
2·2MΩ
1·5kΩ
10kΩ
10kΩ
8μF
2·2kΩ
10kΩ
8μF
8μF
V5 12 AU7
47kΩ
15kΩ
15kΩ
output
h.t. -

Fig. 6. Circuit diagram of the electronic system

THEORY

ist of symbols

x = ground displacement
ξ = displacement of the bob relative to the base
v = output voltage of the phase-sensitive detector
ρ = a constant defined by $v = \rho\xi$
R = value of the feedback resistor
C = value of the damping capacitor
i = current through the feedback coil
A = feedback-coil constant (defined below)
B and S are constants related respectively to the mechanical damping and stiffness of the pendulum (S includes the effect of gravity)
T_N = resonant period of the pendulum with no feedback
T_F = resonant period of the pendulum with feedback
$\omega_N = 2\pi/T_N$
$\omega_F = 2\pi/T_F$
n = damping coefficient of the pendulum with feedback
U = frequency response function of the instrument, that is, the amplitude response to an angular frequency ω relative to the nominal response
Integrator circuit symbols are shown in Fig. 8

$$\left.\begin{array}{l}\dot{x} \text{ is the first time derivative of } x\\ \ddot{x} \text{ is the second time derivative of } x\end{array}\right\} \text{similarly for other variables}$$

The feedback-coil constant A is defined such that the force produced on the pendulum by a current i through the coil is equal to that produced by a constant ground acceleration of Ai. But

$$i = v/R + C\dot{v} = (\rho/R)\xi + \rho C\dot{\xi}$$

Thus, the equation of motion of the pendulum is

$$\ddot{\xi} + (B + A\rho C)\dot{\xi} + (S + A\rho/R)\xi = -\ddot{x} \qquad (1)$$

which gives the resonant angular frequency of the pendulum:

$$\omega_F = \sqrt{(S + A\rho/R)} \qquad (2)$$

With no feedback (that is, with R infinite) this becomes

$$\omega_N = \sqrt{S}$$

and hence
$$\rho = (R/A)(\omega_F^2 - \omega_N^2) \qquad (3)$$

(This equation is used for substituting more easily measured quantities for ρ.)
The damping coefficient n is

$$n = \tfrac{1}{2}(B + A\rho C)/\omega_F$$

In practice, the natural damping of the pendulum will be small, so that $B \ll A\rho C$, and

$$n \simeq \tfrac{1}{2}A\rho C/\omega_F$$
$$= \tfrac{1}{2}\omega_F CR(1-\omega_N^2/\omega_F^2) \qquad (4)$$

The value of n which gives optimum frequency response is approximately 0·6, so

$$C = 0{\cdot}191 T_F[R(1-T_F^2/T_N^2)]^{-1} \qquad (5)$$

The response of the pendulum to a sinusoidal ground oscillation $x = X\cos\omega t$ is

$$\xi = [-\omega^2 X \cos(\omega t+\theta)][(\omega_F^2-\omega^2)^2+4n^2\omega_F^2\omega^2]^{-\frac{1}{2}} \qquad (6)$$

where $\tan\theta = 2n\omega_F\omega/(\omega_F^2-\omega^2)$.

When $\omega \ll \omega_F$, which is approximately true for sea-wave generated microseisms in the present instrument, the nominal response is obtained and is

$$\xi \simeq -\omega^2 X\cos\omega t/\omega_F^2 = \ddot{x}/\omega_F^2 \qquad (7)$$

and $$v = \rho\xi \simeq \ddot{x}\rho/\omega_F^2$$

Using equation (3), the nominal sensitivity of the accelerometer is thus

$$v/\ddot{x} = (R/A)(1-\omega_N^2/\omega_F^2)$$
$$= (R/A)(1-T_F^2/T_N^2) \qquad (8)$$

This, incidentally, shows the effect of negative feedback in reducing dependence on the amplifier gain since, as the feedback is increased, T_F^2/T_N^2 becomes smaller and the sensitivity becomes dependent almost entirely on the ratio R/A.

From equations (6) and (7), the amplitude response relative to the nominal amplitude response is

$$U_1 = [(1-\omega^2/\omega_F^2)^2+4n^2\omega^2/\omega_F^2]^{-\frac{1}{2}} \qquad (9)$$

where $n = 0{\cdot}6$ if optimum damping is used.

A diagram of the integrator circuits is shown in Fig. 7. R_1 includes the output resistance of the previous circuit (approximately 30 kΩ with the feedback connected) and R_3 includes the output resistance of the triode amplifier V_4 (approximately 25 kΩ from each anode). The response of this circuit is

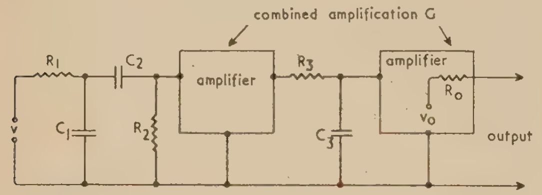

Fig. 7. Diagram of the integrator circuit for calculation of the frequency response

$$\frac{v_0}{v} = G\left\{\left[\left(1+\frac{R_1}{R_2}+\frac{C_1R_1}{C_2R_2}\right)+\right.\right.$$
$$\left.\left.+j\left(\omega C_1R_1-\frac{1}{\omega C_2R_2}\right)\right](1+j\omega C_3R_3)\right\}^{-1} \qquad (10)$$

When ωC_1R_1, ωC_2R_2 and ωC_3R_3 are large compared with 1, v_0/v becomes the nominal response of the circuit:

$$\left(\frac{v_0}{v}\right)_{\text{nominal}} = -\frac{1}{\omega^2}\frac{G}{C_1R_1C_3R_3} \qquad (11)$$

which represents a double integration, as explained abo Thus nominally

$$v_0 = \frac{G}{C_1R_1C_3R_3}\iint v\,dt^2$$

and using equation (8), the overall nominal sensitivity is

$$\frac{v}{X} = \frac{G}{C_1R_1C_3R_3}\cdot\frac{R}{A}\left(1-\frac{T_F^2}{T_N^2}\right) \qquad (1$$

From equation (10), the actual amplitude response of t integrator circuits relative to the nominal response is

$$U_2 = \frac{|v_0/v|}{(v_0/v)_{\text{nom.}}} = \left\{\left[\left(1-\frac{1}{\omega^2C_1R_1C_2R_2}\right)^2+\right.\right.$$
$$\left.+\frac{1}{\omega^2}\left(\frac{1}{C_1R_1}+\frac{1}{C_1R_2}+\frac{1}{C_2R_2}\right)^2\right]\left(1+\frac{1}{\omega^2C_3^2R_3^2}\right)$$

The overall amplitude response function U is the produ of the right-hand side of equations (9) and (13) and is plott in Fig. 8.

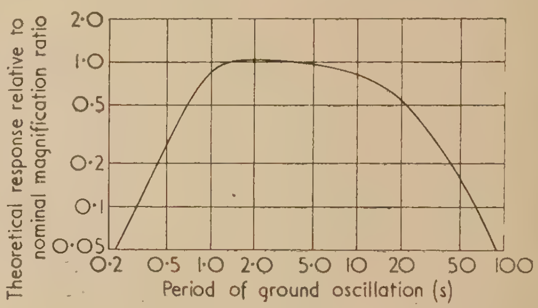

Fig. 8. Frequency response of the instrument

The absolute phase response is not important in micr seism studies, since it is the relative phase between differe instruments which is used and usually they will be arrange to have similar characteristics. However, the phase respon may be calculated, if required, from equations (6) and (1C

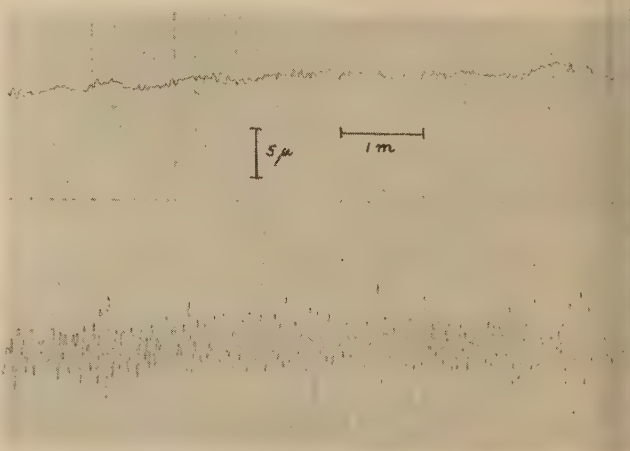

Fig. 9. Records from the seismograph showing a quiet period on 16 November, 1957, and a period of moderately large activity on 19 November, 1957, due to a storm in the North Atlantic Ocean

DETERMINATION OF CONSTANTS

The constants required are those contained in equations , (9), (12) and (13), that is, A, R, T_F, T_N, G and the values C_1, C_2, C_3, R_1, R_2 and R_3.

The constant A is determined as follows. The feedback il is disconnected and the instrument levelled till the output the phase-sensitive rectifier is zero. The instrument is then ted through a known angle ϕ using the levelling screws, ich is equivalent to applying a steady horizontal accelera- n of $g\phi$. A current i from an external source is then passed rough the feedback coil and adjusted till the output of the ase-sensitive rectifier is again zero. Then $g\phi = Ai$.

T_F is determined by disconnecting the damping capacitor d measuring the period of oscillation with a stop-watch. $_N$, the period without feedback, is determined similarly but ith the feedback resistor also open-circuited. The test switch which allows these measurements to be made has been omitted from the circuit diagram (Fig. 6) for the sake of simplicity. The amplifier gain G is measured by connecting a known d.c. voltage between the grids of V_4, and measuring the output voltage produced using a high-resistance meter. The resistors and capacitors are measured on a bridge in the usual way.

REFERENCES

(1) Darbyshire, J. *Proc. Roy. Soc. A*, **202**, p. 439 (1950).
(2) Donn, W. L., and Blaik, M. *Bull. seismol. Soc. Amer.*, **43**, p. 311 (1953).
(3) Darbyshire, J. *Proc. Roy. Soc. A*, **223**, p. 96 (1954).
(4) Benioff, H. *Advances in Geophysics*, **2**, p. 219 (New York: Academic Press Inc., 1955).
(5) Tucker, M. J. *Electronic Engng*, **24**, p. 420 (1952).
(6) Tucker, M. J. *Electronic Engng*, **25**, p. 35 (1953).

An instrument for the determination of potassium in sodium chloride

By G. H. Laycock, B.Sc., A.Inst.P.,* Imperial Chemical Industries Ltd., Nobel Division, Stevenston, Ayrshire

[*Paper first received* 9 *December*, 1957, *and in final form* 19 *February*, 1958]

An instrument has been designed to measure the percentage of potassium in a 2·4 g sample of sodium chloride crystals in the range 0–4% with an accuracy of ±5%. A determination, which takes one minute, is made by recording photoelectrically the light scattered by suspended particles of potassium cobaltinitrite obtained by the addition of sodium cobaltinitrite solution to the dissolved sample. The instrument, which includes a novel device for dispensing a fixed quantity of reagent, can be used to determine the percentage of other impurities in other substances by selecting suitable reagents.

he instrument described is used in a potassium nitrate plant n which potassium nitrate is made by the double decomposition of sodium nitrate solution with potassium chloride. fter some evaporation, the plant liquor is in the form of otassium nitrate solution containing a suspension of sodium hloride crystals.

The sodium chloride crystals are extracted in a centrifuge nd the potassium nitrate solution is evaporated and purified. or efficient operation it is necessary that the percentage of otassium in the sodium chloride by-product shall be kept t a minimum.

Before the introduction of the instrument described, a nanual test was used in which a weighed sample of crystals vas dissolved in a measured quantity of water. The solution vas filtered and the potassium content precipitated by the ddition of excess sodium cobaltinitrite solution. This uspension of potassium cobaltinitrite was separated in a aboratory centrifuge and the volume of the solid was then neasured. This test was accurate to 10% in the range -4% potassium and took more than ten minutes to carry ut; its main drawback was its slowness.

PRELIMINARY INVESTIGATION

An instrument was required to make a rapid measurement. he use of a flame photometer, and the use of a counter neasuring the radioactivity of potassium were both investiated as possible bases for a measuring instrument, and both vere found to be unsatisfactory. It was then decided to build an instrument to carry out the manual test rapidly and automatically. A series of preliminary experiments provided the following information.

To within an accuracy of 2·5%, a volume of salt could be measured with a scoop and the weighing operation could thus be eliminated. A constant flow of water could be used to replace the measurement of a fixed quantity of water.

A light absorption method could not be used to measure the quantity of potassium cobaltinitrite precipitated after adding excess sodium cobaltinitrite reagent, since the reagent was a dark orange colour and absorbed almost as much light as the orange coloured precipitate. A light scattering method could, however, be used, and the light absorbed by the reagent before and after scattering would cause no error if the subsequent instrument was calibrated using samples of salt of known potassium content.

It would be unnecessary to filter dirt from each sample since the dirt was in the form of a few relatively large particles, whilst the precipitate was in the form of far more numerous particles of the order of 10 μ, and the dirt particles would therefore have very little effect on the total light scattered. The average precipitate particle size did not vary significantly in the temperature range 5–15° C. This was the expected variation in water supply temperature. An instrument was designed and built using this information.

THE INSTRUMENT (FIG. 1)

The instrument was contained in a stainless steel box 16 in. wide × 13 in. high × 9 in. deep with a door at the front and a small lid on top. A continuous constant flow of

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250 cm³/min of water was obtained from a constant head tank mounted 8 ft above the instrument. The water passed through a 1 mm mesh filter and a capillary restrictor 8 cm long and 1·64 mm bore mounted in the instrument case. The water flowed under gravity into and through a stirred stainless steel mixing pot and through a glass measuring cell and out to drain. The drain was luted to maintain a constant head in the measuring cell. To operate the instrument a sample of salt measured in a scoop and weighing 2·4 g ± 2·5% was tipped through the hole at the top of the instrument into the mixing pot. The action of lifting the lid over the hole drove a fixed volume of 6 cm³ of sodium cobaltinitrite reagent into the mixing pot. This pot was stirred with an air jet, causing the salt to be dissolved rapidly and the potassium content to be precipitated. The suspended precipitate flowed over into the glass measuring cell. A beam of light was projected through this cell and light scattered from the precipitate was measured with a photocell. The continuous water flow washed out the precipitate ready for the next test. The beam of light was from a 12 V 24 W car headlamp bulb supplied from a 230 V 50 c/s supply through a step-down transformer. The beam was focused using a simple 1 in. diameter convex lens of 2 in. focal length. The focus was adjustable in three dimensions by a screw mechanism making up the lamp holder support. The glass measuring cell was totally enclosed in a small stainless steel box to prevent stray light entering and reaching the photocell. The focus adjustment was viewed on a ground glass screen behind the glass cell, the adjustment being correct when a circle of light just filled the screen.

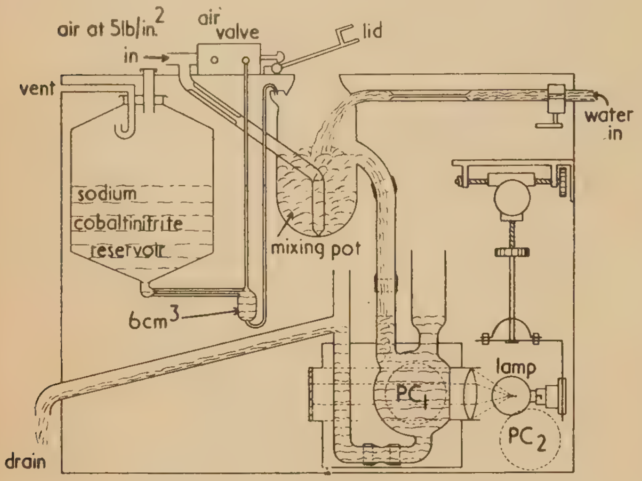

Fig. 1. Diagram of instrument for the determination of potassium in sodium chloride

PC_1, photocell viewing precipitate; PC_2, photocell viewing lamp directly.

The fixed quantity of sodium cobaltinitrite was supplied by a novel arrangement in which a 6 cm³ vessel was connected to a 1·5 l, reservoir by a capillary 2 cm long and 1·0 mm bore. When the air valve was open, 5 lb/in.² air pressure was applied to the top of the 6 cm³ vessel and the 6 cm³ of reagent was blown over into the mixing pot by way of a 0·1 in. bore tube. The air pressure was sufficient to prevent more reagent from flowing from the reservoir. When the air valve was closed the 6 cm³ vessel was vented to atmosphere and refilled under gravity. This complete dispenser was made in 18/8 titanium stainless steel.

The mixing pot was of stainless steel and had ¼ in. bo tube entries for water, reagent, and air and ½ in. bore ov flow. The air tube extended to the bottom of the pot a was terminated in a jet. The hole at the top of the pot w 1 in. diameter. The curved shape of the pot, devised by tr and error, ensured that the stirring would effectively preve the build-up of precipitate, dirt or undissolved salt. T volume of the pot below the overflow was 30 cm³.

The glass measuring cell was made with three flatten sides to prevent stray reflexions reaching the photocell a to prevent distortion of the light beam. It had a volume 30 cm³. The inlet was offset from the centre of the top the measuring cell so that the liquid flow tended to swirl a vertical plane and prevented settling and deposition precipitate. This shape was arrived at by trial and erro The vent tube at the top was provided as an outlet for bubbles which would otherwise interfere with the light bea It was found that dirt collected in this tube at the liqu surface, but was easily removed. A template was made that identical replacement cells could be made.

The sizes and flows used were based on the requiremen that the test should be completed in one minute and that t amount of reagent used should be a minimum. The amou of reagent required to precipitate the maximum expect amount of potassium in a 2·4 g sample of salt was found be 6 cm³. The water flow of 250 cm³/min caused the liqu in the mixing pot to be changed in seven seconds, and further ten seconds elapsed before a volume change w completed in the glass measuring cell.

THE ELECTRICAL MEASURING SYSTEM

The null balance servomechanism and slide-wire of recording potentiometer were used to compare the e.m from the photocell facing the glass measuring cell with th e.m.f. from a second photocell directly illuminated by th lamp (Fig. 2). Variations in light output from the lam affected both photocells equally and a stabilized powe supply for the lamp was thus unnecessary. The photocel were matched 30 mm diameter barrier layer cells. Thi circuit was arranged so that the photocells were run a optimum conditions of linearity of e.m.f. output for ligh input by having each cell connected across 200 Ω. The e.m.

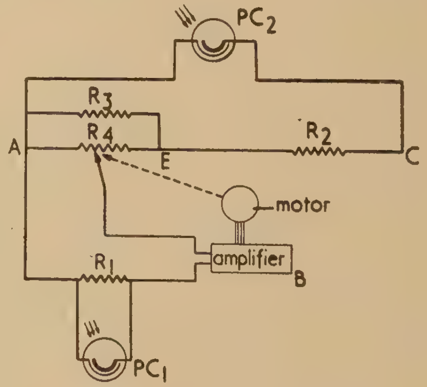

Fig. 2. The electrical circuit

$R_1 = 200\ \Omega$
$R_2 = 194\ \Omega$
$R_3 = 8{\cdot}9\ \Omega$
$R_4 = 20\ \Omega$ slide-wire.
PC_1 = photocell viewing precipitate.
PC_2 = photocell viewing lamp directly.

ross AB was 200 μV when there was no precipitate going rough the cell. The output across AB was 4 mV giving ll-scale deflexion of the instrument when a 4·0% potassium mple was passing through the glass cell. The output of the cond photocell was 130 mV measured across AC.

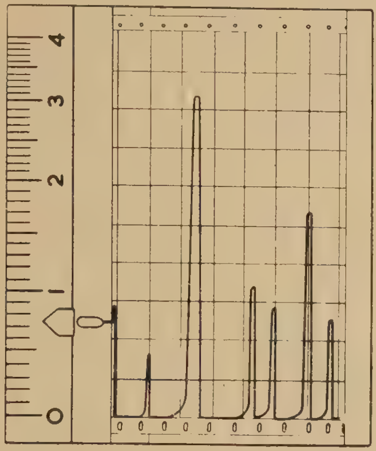

Fig. 3. The recorder scale and chart

The e.m.f. from the measuring photocell PC_1 was proortional to the amount of scattered light from the precipitate hich was proportional to the number of particles and so to ıe weight of precipitate. This was therefore proportional) the percentage of potassium. The pen of the recorder was onnected mechanically to the slider of the slide-wire so that, s the recorder chart was driven at a constant speed past the en, a trace was obtained as shown in Fig. 3. For each sample of salt, as the precipitate started to flow from the mixing pot to the glass cell the recorder trace rose sharply to a peak, and then decreased as the precipitate was washed away, until it reached the base-line with only water passing through the glass cell. The height of the peak was taken as the measure of the percentage potassium in the sample. The instrument was calibrated by putting samples of salt containing known percentages of potassium through the instrument. The instrument scale was found to be non-linear (see Fig. 3).

The recorder was useful in that not only did it keep a permanent record of the percentage of potassium in each sample, but it also showed the time at which the process man took each sample.

Range adjustment could be carried out in any of three ways:

(i) adjust the ratio of resistance across AE to that across AC, keeping the resistance across AC constant;
(ii) limit the light to photocell PC_2 by placing an iris diaphragm between it and the lamp;
(iii) move photocell PC_2 nearer to, or further from, the lamp, thereby varying the amount of light received by the cell and its e.m.f.

The third method was found to be the best and was used in the instrument. Photocell PC_2 was mounted on a sliding base with a clamp fitted to it.

The automatic potentiometer recorder which was modified for use with the instrument had a five-second response-time for full-scale deflexion, and a chart speed of 2 in./h. The plant was run on a three-shift system and the instrument was run continuously.

The instrument has also been used to measure impurities in other materials using various reagents. Its accuracy over a long period is ±5%.

An electrodeless method for the measurement of electrolytic conductivity and magnetic susceptibility

By W. R. Myers, M.Sc., A.Inst.P., Physical Laboratory, University of Southampton

[*Paper first received* 30 *September*, 1957, *and in final form* 6 *February*, 1958]

Simultaneous measurement of electrolytic conductivity and magnetic susceptibility is achieved by observing the changes in output voltage of a transformer when its air core is filled with a specimen. Conductivity measurements for strong electrolytes have been obtained in which departures from accepted values are less than 0·07 mho m^{-1} in the range 1 to 30 mho m^{-1}. The magnetic measurements generally have less precision, and errors of 2% occur for susceptibilities of the order of 10^{-11} H/m.

he method is dependent upon the variation of output oltage of a transformer with the electric and magnetic roperties of the core. A generator of sinusoidal e.m.f. upplies two similar air-cored transformers in series, the econdary windings being connected in series opposition so hat there is only a small output voltage. By means of a uitable resistance-capacitance network, the voltage across ıe secondary of one transformer is altered until the utput is zero. On placing a specimen in one of the ansformer cores, the voltage balance is destroyed. A esistance in the R–C network is then adjusted to give ninimum output voltage. The change in resistance is roportional to the conductivity of the specimen, whilst the residual output voltage is a measure of the magnetic susceptibility.

APPROXIMATE THEORY

Fig. 1 illustrates the basic circuit. For any pair of similarly constructed transformers, the secondary voltages V_1, V_2 will be approximately the same in amplitude and almost in phase opposition. Let us assume that $|V_2| < |V_1|$ and that V_2 lags with respect to V_1 by phase angle slightly less than π; this may easily be achieved in practice by adjustment of the transformer windings. Under these circumstances for the apparatus described, adjustment of the resistance R and the capacitance C enables the voltage V_2' to be made equal in amplitude and in exact anti-phase with the voltage V_1; the output voltage V_0 is then zero.

If the effects of stray reactance be ignored

$$V_2' = \frac{1/jpC}{R + jpL + 1/jpC} \cdot V_2 \qquad (1)$$

where L is the effective inductance of the secondary winding of the transformer T_2, and p is the pulsatance. It follows that

$$|V_2'/V_2| = (1 - 2p^2LC + p^2C^2R^2 + p^4L^2C^2)^{-\frac{1}{2}} \qquad (2)$$

and the difference in phase is

$$\angle V_2' - \angle V_2 = -\tan^{-1} pCR/(1 - p^2LC) \qquad (3)$$

For the apparatus described, the amplitude and phase relationships reduce to

$$|V_2'/V_2| = 1 + p^2LC \qquad (4)$$

and

$$\angle V_2' - \angle V_2 = -\tan^{-1} pCR \qquad (5)$$

Variation of R thus causes a linear change in phase, yet has a negligible effect on the amplitude of V_2', whilst variation of C produces a linear change in both amplitude and phase. The output voltage V_0 may therefore be reduced to zero by successive adjustment of R and C.

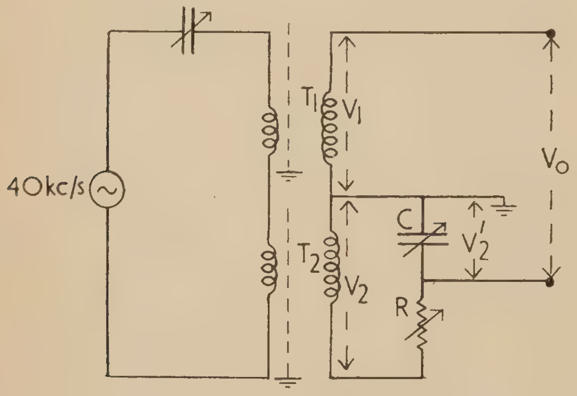

Fig. 1. Supply and balancing circuit

On changing the core of one of the transformers, the permittivity, conductivity and magnetic susceptibility each affect both primary and secondary voltages. The change in permittivity causes capacitance changes, but these may be reduced to negligible proportions by the use of electrostatic screens. Eddy currents in a conducting specimen involve power dissipation which is equivalent to increased primary circuit resistance, but for electrolytic conductivities, this change is extremely small. It may be shown that the magnetic field distribution is modified by the eddy currents in such a way that the amplitude of the average field is reduced and a phase retardation appears (see, for example, Warren(1)). The change in amplitude is very small, whilst the phase change, which is apparent in the secondary voltage V_2, is directly proportional to the conductivity of the specimen. Finally, the amplitude of the voltage V_2 is directly dependent on the magnetic flux and hence on the susceptibility of the specimen. The major effects of an electrolyte on the secondary voltage V_2 are therefore (i) to shift the phase in proportion to the conductivity, and (ii) to alter the amplitude in proportion to the magnetic susceptibility. Neglecting second-order effects, the change in R necessary to minimize V_0 is therefore a measure of the conductivity, whilst i minimal voltage V_0 depends directly upon the magne susceptibility.

APPARATUS

Fig. 2 is a block diagram of the apparatus. The volta balancing is highly frequency-sensitive and this necessita the use of a crystal-controlled generator. A frequency 40 kc/s was chosen as convenient for conductivity measu ments of simple electrolytes. The primary windings of

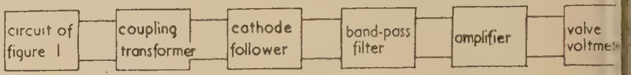

Fig. 2. Block diagram of apparatus

transformers T_1 and T_2 are fed in series from the genera through a variable capacitor which tunes the circuit resonance. The design of suitable transformers deper upon the volume of the liquid specimens, and as it w intended only to investigate the capabilities of the meth with common substances, it was possible to employ la cylindrical formers some 10 cm long and 3·5 cm in diamet These were thin-walled tubes of silica for which the therr expansion coefficient is very small. Directly upon ea former was wound first, an electrostatic screen, then secondary coil, being a single layer of 138 turns occupyin length of 7·5 cm, next another electrostatic screen a finally a primary winding of forty-five turns. The t transformers are mounted in separate compartments of rigid Duralumin structure so that they are electrica screened from each other and from their surroundings, a the assembly is housed in a thermally insulated box in orc to reduce temperature fluctuations. The balancing netwo is also enclosed in a partially insulated, screened box.

The output of the balancing circuit is taken *via* a hi impedance 1 : 1 ratio screened transformer to a catho follower, thence through a band-pass filter to elimina harmonic frequencies arising from the generator; finally, t signal is amplified by a narrow bandwidth amplifier. T signal voltage is measured with a valve voltmeter, and, addition, a cathode-ray oscilloscope is used for rapid detecti of minimum signal.

OPERATION AND MEASUREMENTS

Power dissipation in the primary windings of the tran formers causes an initial temperature rise when the generat is switched on. After about half an hour the temperatu distribution in the transformers becomes steady and sm fluctuations of room temperature have little effect on t output voltage as they are heavily attenuated by the therr insulation of the surrounding box.

The liquid specimen is admitted to a glass test tube so 2·3 cm in diameter which rests in an insulating tube with one of the transformers. The resistance R is slightly reacti and when it is adjusted, V_2' changes in amplitude as well in phase. This does not appreciably affect the conductivi measurement, but it causes an uncertainty in the suscep bility measurement. A correction can be applied for th effect, but for high conductivities (20 mho m^{-1}) it is abo 15% of the susceptibility of water. In practice, the change reactance is roughly proportional to the change in resistan and the effect could be eliminated by using a variable resist of constant reactance.

Several observations were made at room temperatures for ueous solutions of potassium chloride and sodium chloride concentrations between 1 and 20% by weight. The conctivity of a 20% aqueous potassium chloride solution was umed to be 27·67 mho m^{-1} at 20° C; the ratios of istance changes then gave the conductivities of all samples within 0·07 mho m^{-1} of accepted values. On measuring conductivity of a given solution several times in succession, consistency of results was within 0·04 mho m^{-1}.

Accurate measurement of conductivity, even for weakly nducting solutions, would be possible if either the diameter the specimens or the frequency of the supply were reased, but it is unlikely that the method would be suitable conductivities much below 10^{-1} mho m^{-1}. In comrison with some other electrodeless methods for measuring nductivity (e.g. Gupta and Hills(2)), the accuracy is not gh, although some improvement could be achieved. Here, attempt at simultaneous estimation of two physical operties inevitably increases the errors.

For the magnetic measurements, distilled water was employed as standard and, after applying empiral corrections for the reactive effects of the resistance R, the results were within $0 \cdot 3 \times 10^{-12}$ H/m of accepted values. The magnetic measurement becomes more certain as conductivity decreases, because the correction becomes smaller, and for a few organic liquids which are good insulators, errors in the measured susceptibilities were less than $0 \cdot 15 \times 10^{-12}$ H/m.

ACKNOWLEDGEMENT

The author wishes to thank Prof. A. M. Taylor for help with this paper and for the laboratory facilities.

REFERENCES

(1) Warren, A. G. *Mathematics Applied to Electrical Engineering*, p. 252 (London: Chapman and Hall Ltd., 1939).

(2) Gupta, S. R., and Hills, G. J. *J. Sci. Instrum.*, **33**, p. 313 (1956).

A beam-scanned rotating heavy-ice target for high loads

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From the several possible targets for the D(d, n)^{3}He reaction the heavy-ice target proves to be the most suitable for outputs of about 10^{10} neutrons per second. Beam scanning in two perpendicular directions combined with rotation of the target is found to be necessary to secure a sufficient life of the ice surface.

1. INTRODUCTION

or the investigation of the biological effects of fast neutrons, ie D(d, n)^{3}He is a very suitable reaction. There is no iclear γ-radiation, and the energy dispersion of the neutrons ie to the thickness of the target is not excessive at bombardg energies of 1 MeV, even with a thick target. The main ifficulty consists in getting a sufficiently high yield. Using thin, heavy ice target a flux of neutrons, monoenergetic in ich direction, is obtained. For example, a 1 MeV deuteron eam produces 4·15 MeV neutrons in the forwards direction id 1·77 MeV neutrons in the backwards direction, with itermediate values in the other directions. With a 0·2 MeV euteron beam the neutron energy limits are 3·06 and ·06 MeV. A survey of the experimental and theoretical esults, together with an energy nomograph according to L. McKibben, is given by Hanson, Taschek and Williams.(1)

Vhen a thick heavy ice target is bombarded with deuterons iese particles are slowed down in the ice layer. As in the -1 MeV region the cross-section for neutron production icreases approximately linearly with the energy of the icident particle, most of the neutrons are produced at euteron energies near to that of the incident beam. With a MeV incident deuteron beam about 50% of the neutrons re produced at deuteron energies above 0·75 MeV. To ave reasonable exposure times a total flux of 10^9–10^{10} eutrons per second is desirable.

From the data of Hunter and Richards(2) and of Wenzel nd Whaling(3) one can calculate that, for a yield of 0^{10} neutrons per second, with a thick heavy-ice target, a deuteron beam current of 0·25 mA at 1 MeV is necessary, or 0·42 mA at 0·8 MeV. This output can be achieved with the equipment developed in this laboratory.(4)

2. ALTERNATIVE DEUTERIUM TARGETS

The main factors determining the suitability of deuterium targets concern the yield, life and simplicity. For the yield one can give a rough figure of merit assuming it to be equal to the ratio of the number of deuterium atoms per molecule to the sum of the atomic numbers of atoms in the molecule. For the various possible target materials the yield appears to be: deuterium gas 1; heavy paraffin (C_nD_{2n+2}) about 0·25; D_2O, 0·20; D_3PO_4, 0·060; NaOD, 0·050; ZrD_2, 0·048; TiD, 0·043; ZrD, 0·024; TaD, 0·014; for targets consisting of a metal in which a certain amount of deuterium is accumulated as the result of deuteron bombardment, the yield will generally be less than 0·02.

The disadvantage of the large depth required for the gas target is compensated by the large yield. Between the gas chamber of the accelerating tube either a very thin and well-cooled foil is necessary, with its inherent loss of deuteron energy, or a very well focused beam through a number of small apertures together with an elaborate pumping system.(5) Targets of heavy paraffins (C_nD_{2n+2}) involve neutrons of large energy dispersion as a result of the accompanying ^{12}C(d, n)^{13}N reaction.

Experiments with a solid NaOD target have shown that the hydroxide is burned by the beam. In the molten state the hydroxide decomposes and special pumping near the target is required to remove the liberated gases. Similar objections hold for D_3PO_4. The main advantage of the zirconium target lies in its simplicity. Penning and Moubis(6) have already pointed out the disadvantage of its short life. Recent developments with zirconium targets show little improvement in this respect. Graves and others(7) report a decrease of the neutron yield by a factor of two after some hours of irradiation. Forbes, Graves and Little(8) report a factor of ten for this decrease of yield. The same results were found by Bergstrahl and others.(9) It can hardly be expected that TiD and TaD targets will be substantially better than the zirconium targets.

The problems to be envisaged with the ice target are related to the relatively high vapour pressure and the low thermal conductivity of ice. The vapour pressure at $-100°$ C is about 10^{-5} mm of mercury. The low thermal conductivity necessitates spreading of the energy to be dissipated over a sufficiently large area of the ice. This can be done by moving the ice layer under the deuteron beam. This offers the possibility of increasing the specific load by making use of the heat capacity of the irradiated area.

A special target has been constructed, consisting of a hollow metal disk, which can rotate about a vertical shaft. An ice layer is frozen between two rims near the edge of the disk, forming a flat annular target. The cooling is effected by the evaporation of liquid air inside the hollow disk. Two sets of deflecting plates, connected to oscillators, cause the beam to scan the ice surface over an area of approximately 5 cm.^{2}

Before going into details of the target construction, problems of heat dissipation will be discussed.

3. PROBLEMS OF HEAT DISSIPATION

3.1 The first point of interest is the time Δt in which a beam of a given current density raises the temperature of the irradiated ice layer from $-180°$ C (temperature of the liquid air-cooled disk) to $-100°$ C, the temperature where the vapour pressure of ice is 10^{-5} mm of mercury. The average specific heat of ice in this temperature range amounts to $0{\cdot}26$ cal/g × °C. (It is assumed that the beam hits the target perpendicularly to the ice surface.)

The density of heavy ice is $1{\cdot}0$. If d represents the range in centimetres of the deuterons in ice and S the specific target dissipation in calories per second per square centimetre, then:

$$\Delta t = (80 \times 0{\cdot}26 \times d)/S \text{ (seconds)} \tag{1}$$

With D_1^+ ions of 1 MeV, a beam current of 300 μA and a beam diameter of $0{\cdot}36$ cm, S amounts to 720 cal s^{-1} cm^{-2}. As $d = 19 \cdot 10^{-4}$ cm for 1 MeV deuterons $\Delta t = 5{\cdot}5 \times 10^{-5}$ s.

There may also be D_2^+ and D_3^+ ions in the beam giving a still shorter time, owing to shorter ranges.

No attention has been paid to the thermal conduction. From paragraph 3.2 this appears justified for times shorter than, say, 10^{-4} s. It is assumed that dE/dx remains constant along the beam path. This would imply that the range increases linearly with the energy. We can accept this for a rough calculation, for example the range of 1 MeV and $0{\cdot}5$ MeV deuterons is respectively 19 and $8{\cdot}5$ μ. This means that Δt depends only on the current density and not on the energy of the deuterons

$$\Delta t = 0{\cdot}165/J \tag{2}$$

when J is the current density in $\mu A/cm^2$.

3.2 The second point of interest is the speed with wh the ice layer cools down after the load. Suppose we ha an ice layer of a thickness equal to the range d of t bombarding particle, on a metal base of constant temperatu (T_c), with a temperature distribution $T(x, t)$ at $t = 0$, suggested by Fig. 1. It is assumed that after $t = 0$ bombardment stops. The heat conduction equation is the $a^2(\partial^2 T/\partial x^2) = (\partial T/\partial t)$ with $a^2 = c/k\rho$, where c is the therm conductivity of ice, k the specific heat and ρ the density,

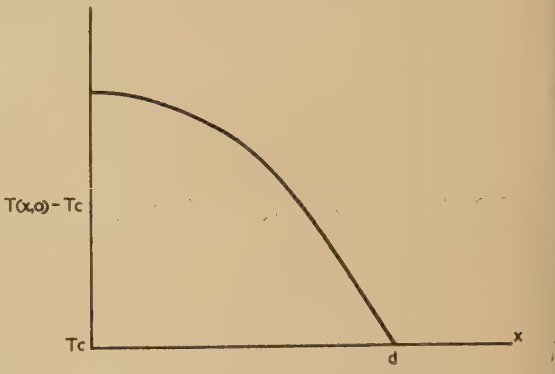

Fig. 1. Assumed temperature distribution at the moment of interrupting the load

The first approximation to the solution of this differenti equation is:

$$T(x, t) - T_c \simeq A\,[\exp(-a^2\pi^2 t/4d^2)]\cos(\pi x/2d),\ 0 \leqslant x$$

where A represents an arbitrary constant.

As the supposed temperature distribution at $t = 0$ can approximated by $A\cos(\pi x/2d)$, it is to be expected that t temperature difference between the surface of the ice lay and the disk decreased by a factor e in about $t' = (4d^2/a^2\pi^2)$ With $d = 19 \times 10^{-4}$ cm, $c = 0{\cdot}0022$ cal s^{-1} cm^{-2} for temperature gradient of 1° C/cm, $k = 0{\cdot}26$ cal/g a $\rho = 1$ g/cm^3, one finds $t' = 1{\cdot}6 \times 10^{-3}$ s. This time giv an idea of the speed of cooling down at the surface for a ice layer of thickness d.

3.3 When an ice layer is loaded with a constant beam, stationary temperature distribution is established as illu trated in Fig. 2. The specific dissipation of the beam in th

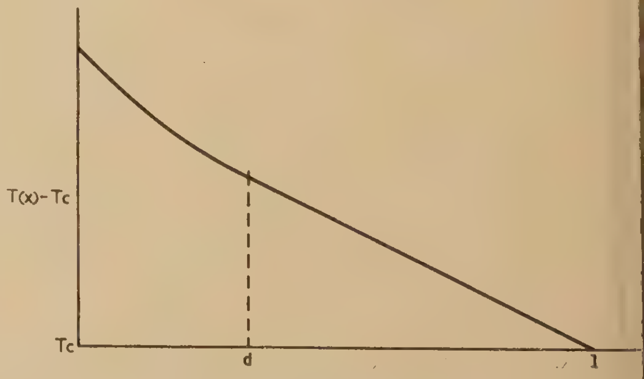

Fig. 2. Temperature distribution in a stationary irrated ice layer; d = range particles

ice is assumed to be so low that the surface temperature lower than $-100°$ C. The range of the ions is d, the thicknes of the layer l, and the temperature of the disk carrying th is constant $T_c = T(l)$. It is again assumed that dE/dx is nstant and that the beam hits the target perpendicularly the ice surface.

For $0 < x < d$ the differential equation is $\partial^2 T/\partial x^2 = S/cd$ 'd for $d < x < 1$, $\partial^2 T/\partial x^2 = 0$.

For $0 < x < d$ the solution is parabolic and for $d < x < 1$ is linear. In this case $T(o) - T(d) = 1\cdot5(S/c)d$ and $d) - T(l) = (1 - d)S/c$, so that $T(o) - T(l) = (1 + 0\cdot5d)(S/c)$. ith 1 MeV deuterons $l = 2d = 38 \times 10^{-4}$ cm, and a nperature difference of 80° C, S amounts to 37 cal s^{-1} cm^{-2} 155 W/cm^2.

For $l = 20d = 0\cdot38$ mm, $S = 19$ W/cm^2.

4. TARGET DESIGN

4.1 It is clear from paragraph 3.3 that in order to operate stationary target with loads of, say, 500 W, by a beam tting the ice surface perpendicularly, the energy has to be read over a sufficiently large surface. This can be accomished by either defocusing the beam or by scanning the am over the ice surface. In the latter case the writing eed of the beam should be such that the heating times lculated in paragraph 3.1 are not surpassed. With a thin yer of 38 μ a surface of a few square centimetres is sufficient, id with a 380 μ layer a surface of a few decades of a square ntimetre will do. In the latter case the neutrons emerge om a rather large area.

The case of a thin (38 μ) layer with higher specific load ıs the disadvantage that sputtering of the ice layer becomes nsiderable.(10) Experiments have shown that an irradiated e film soon gets opaque, probably as a result of cracks due occluded deuterium and thermal stresses and lattice struction. This involves a decrease of thermal conduction. he sputtering losses can be compensated by condensation of esh heavy water vapour on the target, resulting in a kind hoar-frost, as the surface is soon damaged by sputtering such a degree that no homogeneous sheet of ice can grow. he heat conduction of this layer is then much lower than ıat of the original layer.

In consequence of the foregoing considerations it was ecided that, apart from the beam scanning, the effective e area should be increased by rotating the target. In this ay the irradiated ice surface is about thirty times larger nd the neutrons emerge from a spot of acceptable size. et D be the diameter of the beam, A the amplitude of the eam oscillation perpendicular to the movement of the ırget at the irradiated point, and B the amplitude parallel the target movement. Because there is no simple relation etween the oscillation frequencies the whole area of the anned rectangle is covered.

The writing velocity of the beam on the target should xceed $V_{min} = D/\Delta t$; substituting for Δt the value from quation (2) gives $V_{min} = 7\cdot7i/D$, where i is the beam current ı microamperes. With $i = 250$ μA and $D = 0\cdot36$ cm, we nd $V_{min} = 5400$ cm/s.

The minimum scanning frequencies have been chosen as 0^5 c/s, so that with A and $B = 0\cdot5$ cm, the average writing elocity already exceeds 2×10^5 cm/s. In the rectangle overed by the beam the average specific target dissipation hen is $S^1 = (0\cdot24Vi/4AB)$ cal s^{-1} cm^{-2}.

It follows, neglecting the heat conduction, that the heat apacity of the ice layer requires a minimum target velocity V_t t the irradiated area as determined by $V_t\Delta t = 2B$, where rom paragraph 3.1, $\Delta t = (80 \times 0\cdot26 \times d)/S^1$. Substitution ives $V_t = 0\cdot0058Vi/Ad$.

If we assume that V/d is constant, we find $V_t = 3\cdot0i/A$. With $i = 300$ μA and $A = 1$ cm, V_t proves to be 900 cm/s. Considering only the heat capacity of the irradiated ice layer, the value of B does not affect the permissible load. The diameter of the irradiated ice ring is about 25 cm and the target velocity is about 10 rev/min. An irradiated point of the ice surface therefore has a time of $0\cdot1$ s to cool down.

According to the calculations of t' in paragraph 3.2 this time is amply sufficient. In connexion with the thermal conduction, the influence of B proves to be important. With the above mentioned data the target velocity at the irradiated point amounts to 780 m/s so that the heating period of each part of the ice film during a cycle is $2B/780 = 2\cdot6 \times 10^{-3}B$ s. If we compare this time with the "cooling down" time t' calculated in paragraph 3.2 ($1\cdot6 \times 10^{-3}$ s), we see that the thermal conduction allows the maximum permissible target load to be considerably increased if ice layers of a thickness of not more than about d (range of particles) are used. As the loaded ice surface is about thirty times larger than that of a stationary target, damage to the ice layer occurs after a correspondingly longer time. Moreover, these effects do not affect the heat capacity of the ice layer or the limit set to the load by this factor. The same holds for an ice layer in which the losses are restored by condensation of fresh-heavy water vapour.

4. CONSTRUCTIONAL DETAILS

The construction of the target is shown in Fig. 3. On its way to the target disk the beam passes between two pairs of deflector plates B (only one set shown in the diagram) and then through a liquid air trap and a secondary electron suppressor C. The target disk itself is hollow and is cooled by evaporation of liquid air, admitted through a Monel metal tube D passing through a double-walled tube of stainless steel E, which acts as a semi-floating shaft for the target. This shaft has enough flexibility to allow the disk to run quietly. The outer tube remains at room temperature and so freezing of the vacuum seals is avoided. The upper part of the Monel tube rotates in Teflon seals J. The liquid air supply is controlled by a simple compressed air device. The cold air evolved in the hollow disk emerges through a reversed chimney H, directed downward. The draft in this chimney effects at its lower end a hot wire anemometer I, and is indicated on the control panel. In this way the right moment for refilling the target is clearly indicated. The target is driven by a ½ h.p. electric motor through a hydraulic torque converter R, providing speeds of 0–10 rev/s. Heavy water vapour is admitted to the target surface through a special jet G projecting into the target housing. The vapour pressure near the spot where the beam hits the ice is monitored by means of a Penning type manometer (not shown in figure). The target assembly is insulated electrically from earth by means of a simple O-ring N. The whole target assembly can be removed and re-installed without breaking the vacuum in the accelerator tube. The liquid air can be removed and the disk heated to room temperature by admitting dry hot air through the Monel tube.

Each pair of deflector plates is connected to an oscillator. The relation between the peak-to-peak voltage E_2 and the amplitude A or B of the beam on the target is given by

$$A = \tfrac{1}{2}(lL/d)(E_2/E_1)$$

where l is the length in centimetres, d the separation of the deflecting plates, L the distance of the centre of the plates to the target and E_1 the accelerating voltage of the ions. With $l = 10$ cm, $d = 2\cdot5$ cm, $L = 45$ cm, $E_1 = 10^6$ V, $E_2 = 10^4$ V, $A = 0\cdot90$ cm.

The frequencies of the oscillator are 139 and 168 kc/s. The amplitudes are controlled by the voltage of the power pack of the oscillator. In the present experimental arrangement the ions were accelerated by means of a cascade generator. If the power of the oscillator and the transformer of the cascade generator are fed from the same primary voltage, the value of E_2/E_1, and therefore of A, rema constant.

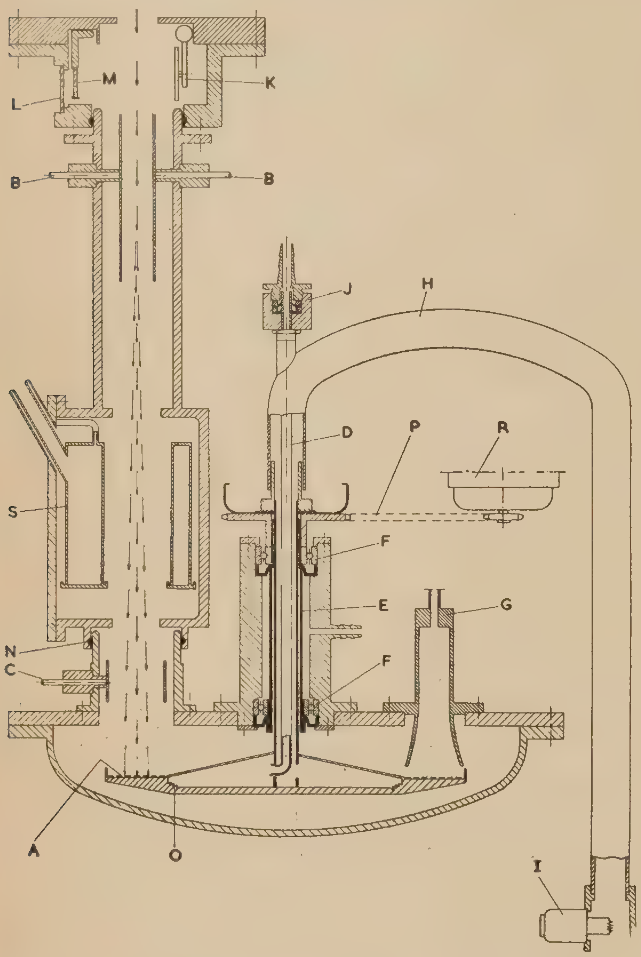

Fig. 3. Rotating heavy-ice target with beam scanning

A, heavy-ice film; *B*, deflectors, two pairs (only one set shown); *C*, secondary electron suppressor; *D*, Monel metal tube for admitting liquid air; *E*, double-wall tube of stainless steel acting as heat insulator and semi-floating shaft; *F*, ball bearings; *G*, heavy-water vapour jet; *H*, reversed chimney; *I*, hot wire anemometer; *J*, Teflon seals; *K*, valve; *L*, window; *M*, revolvable quartz disk for visual beam centring; *N*, insulating vacuum seal; *O*, rims to increase metal-liquid air contact; *P*, chain for driving the target; *R*, torque converter; *S*, liquid air trap.

5. SOME RESULTS

It proves to be possible to operate the target with currents up to at least 600 μA at 800–1000 kV for perio of five hours or more, without any need to renew or rest the ice surface. The amplitudes A and B under these co ditions are 1 to $1\cdot5$ cm, and the target velocity at the pl of the beam is 780 cm/s. Neutron productions more th 2×10^{10} per second were measured with acetylene fil ionization chambers.(4)

Taking into account the heat capacity of the ice only a limiting factor, the admissible load appears to be 260–390 μ In fact, the admissible load is much higher. This is partly to the thermal conduction of the ice and partly small effects not accounted for in the calculations. instance, the beam diameter (about 3–6 mm) was neglect In fact, this means that A and B exceed the substituted valu used in some of the calculations. The energy loss dE/dx smallest at the ice surface, so that the top of the ice surfa after a short irradiation is less heated than the deeper laye Also, the choice of the maximum permissible temperature $-100°$ C is rather conservative.

The consumption of heavy water is small: 1 cm^3 suffi to cover the target with a layer of 25 μ thick, while the ran of 1 MeV deuterons is 19 μ. The heat of evaporation liquid air is 50 cal/g. The consumption of liquid air wit beam of 600 μA and 800 kV accelerating voltage is abo 8 kg/h.

REFERENCES

(1) Hanson, A. O., Taschek, R. F., and Williams, J. *Rev. Mod. Phys.*, **21**, p. 635 (1949).

(2) Hunter, G. F., and Richards, H. R. *Phys. Rev.*, p. 1445 (1949).

(3) Wenzel, W. A., and Whaling, W. *Phys. Rev.*, p. 499 (1952).

(4) van Dorsten, A. C., and Spaa, J. H. *Nuclear Inst ments*, **1**, p. 259 (1957).

(5) Schumacher, B. *Optik*, **10**, p. 116 (1953).

(6) Penning, F. M., and Moubis, J. H. A. *Physica*, p. 1190 (1937).

(7) Graves, E. R., Rodriques, A. A., Goldblatt, M., a Meyer, D. I. *Rev. Sci. Instrum.*, **20**, p. 577 (1949).

(8) Forbes, S. G., Graves, E. R., and Little, R. N. *R Sci. Instrum.*, **24**, p. 424 (1953).

(9) Bergstrahl, T. A., Dunning, K. L., Durand, Ellison, C. H., Howerton, H. K., and Slavin, *Rev. Sci. Instrum.*, **24**, p. 417 (1953).

(10) Bishop, G. R., Preston, G., and Westhead, J. *J. Sci. Instrum.*, **31**, p. 64 (1954).

A high stability mains-operated recording thermistor thermometer

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A simple recording thermometer is described which is mains operated, has a total variation at less than 1% for a mains variation of 10% and a warm up time of less than 5 min. With the given constants full scale deflexion corresponds to 10° F. Any suitable 1 mA recorder may be used.

Wheatstone bridge, incorporating a temperature-sensitive ment, forms the basis of many temperature recorders. e justification for the development of yet another instru-nt was the necessity to record body temperature variations luced during hypothermia experiments. A recorder was quired which would have a brief "warm-up" period, good ng-term stability, and be mains operated without elaborate ltage stabilization.

In the instrument described, any type of thermistor having nominal resistance of 3·3 kΩ may be used and the range ay be varied from a minimum of 10° F full scale, and this ay be located anywhere on the temperature scale within e limits imposed by the thermistor and its mounting.

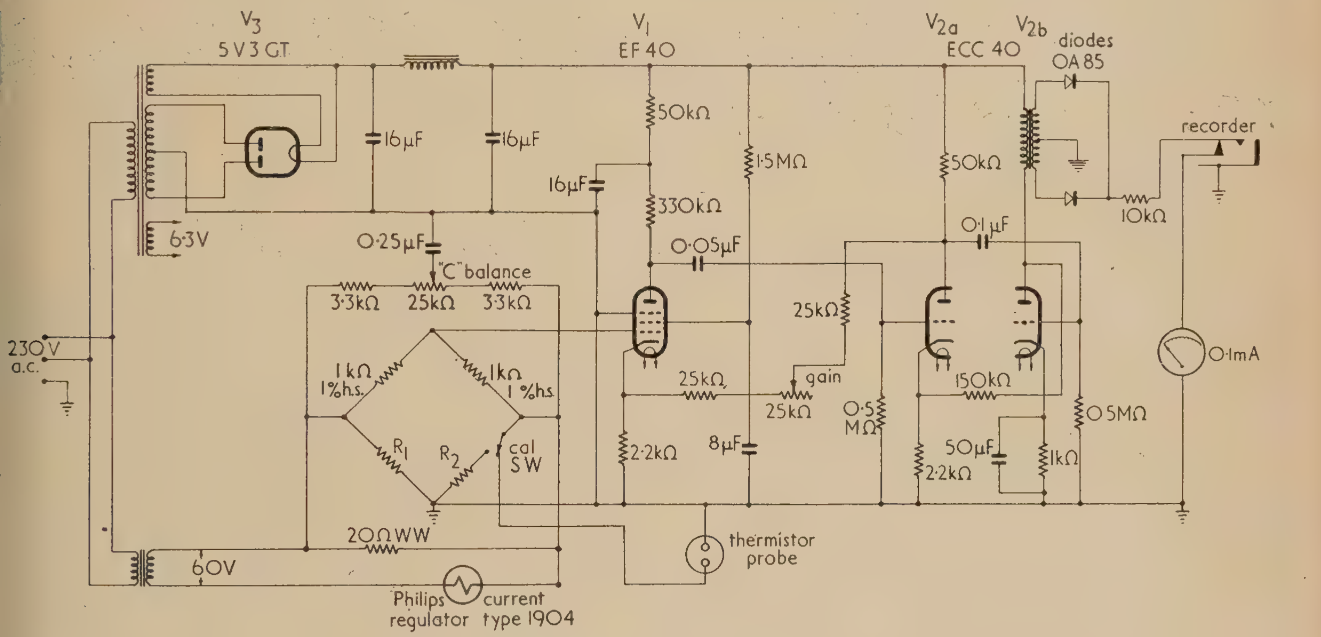

Fig. 1. Circuit diagram of recording thermistor thermometer

The circuit diagram is shown in Fig. 1. The bridge is nergized at mains frequency and the voltage is maintained a current regulating tube, Type 1904 (by Philips Electrical td.), in series with a 20 Ω resistor, across which the bridge connected. At the controlled current of 100 mA this ves a bridge voltage of 2 V, at which the power dissipated the thermistor is approximately 280 μW. For the iniature thermistor type B83203P/3K3 (by Philips Electrical td.), unmounted, this power input would result in a mperature rise of approximately 1° C.* When the ther-istor is mounted in a needle probe, rectal probe, or other assembly having a relatively high thermal capacity and good thermal conductivity to its surroundings, the temperature rise due to self-heating may be neglected. The 50 c/s output from the bridge is amplified by a three-stage highly degenerative amplifier having two current feedback loops and two overlapping voltage feedback loops. The first voltage feedback loop is variable and is used as a full-scale setting control. The minimum gain setting corresponds to 40 dB of feedback giving an overall voltage gain to V_2b anode of 400. D.C. coupled feedback networks are employed to minimize phase shift in the feedback loop and ensure stability at the high levels of feedback used. The voltage gain is practically independent of tube characteristics and variations in mains voltage.

To minimize diode distortion the output transformer is designed to provide 11 V d.c. from the full wave rectifier. When a 0–1 mA recorder (by Esterline Angus) with a coil resistance of 1200 Ω is used, a series resistor of approximately 10 kΩ drops the excess voltage. This confines the diode distortion to the lower 5% of the scale reading. The total variation in output due to mains change of ±10% is less than 1% full scale, corresponding to less than 0·1° F when a span of 10° F is used. The required warm-up time is less than 5 min.

The minimum temperature to be recorded may be set by adjusting R_1 for the particular thermistor being used. R_2 is adjusted to the resistance of the thermistor at the temperature corresponding to full scale, and this may be switched into the bridge to check the full-scale sensitivity of the instrument. Adjustment of gain will be necessary only occasionally. When used as a rectal temperature recorder a Philips thermistor type B83203P/3K3 is embedded in polythene in its glass container as shown in Fig. 2. The time lag of this assembly is approximately 15 s. An alternative assembly is shown in Fig. 3, in which a thermistor bead type B83202P/3K3 has been installed in the tip of a 20-gauge hypodermic needle. The thermistor is cemented in with Araldite (by Aero Research Ltd.) and is in good thermal contact with the needle tubing. The time lag with this assembly is between 1 and 2 s.

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* N.T.C. Resistors (London: Philips Electrical Ltd.).

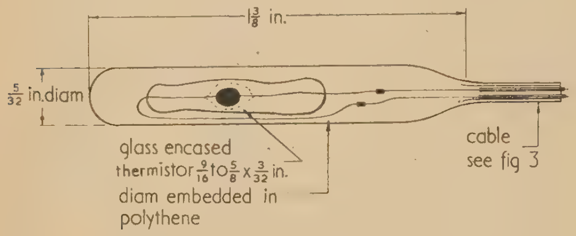
$1\frac{3}{8}$ in.
$\frac{5}{32}$ in.diam
glass encased thermistor $\frac{9}{16}$ to $\frac{5}{8}$ x $\frac{3}{32}$ in. diam embedded in polythene
cable see fig 3

Fig. 2. Arrangement for use as rectal temperature recorder

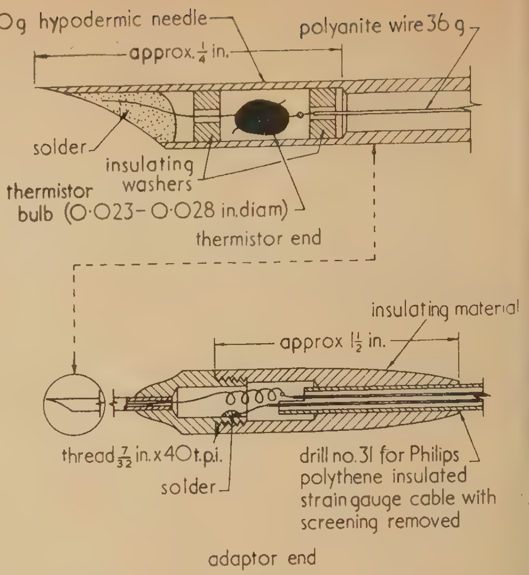
20g hypodermic needle
polyanite wire 36 g
approx. $\frac{1}{4}$ in.
solder
insulating washers
thermistor bulb (0·023–0·028 in.diam)
thermistor end
insulating material
approx $1\frac{1}{2}$ in.
thread $\frac{7}{32}$ in. x 40 t.p.i.
solder
drill no.31 for Philips polythene insulated strain gauge cable with screening removed
adaptor end

Fig. 3. Alternative arrangement in hypodermic needl

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The author would like to acknowledge the able assistan of Mr. J. W. Boyes in making up the temperature prob described in this report.

Laboratory and workshop notes

A double layer-line screen for Weissenberg photography

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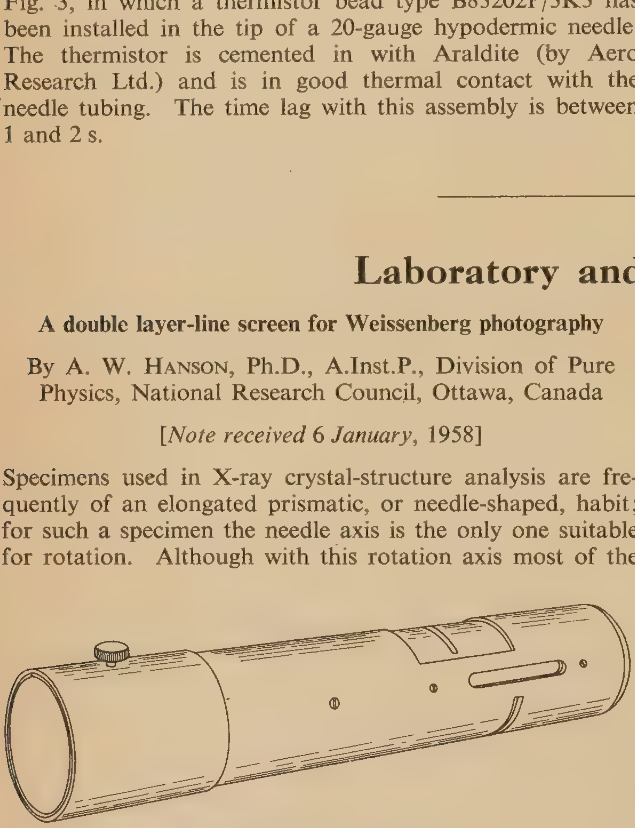
[*Note received* 6 *January*, 1958]

Specimens used in X-ray crystal-structure analysis are frequently of an elongated prismatic, or needle-shaped, habit; for such a specimen the needle axis is the only one suitable for rotation. Although with this rotation axis most of the accessible reflexions can be recorded on zero- and upper-level Weissenberg photographs, the determination of the scale factor appropriate to each level usually presents a problem. One solution is to use a double layer-line screen in order to record simultaneously, on the two halves of the film, two different levels of the reciprocal lattice. The essential mechanical details of such a screen are shown in the accompanying sketch; the upper slit is contained in a hemicylindrical shell which slides within the outer cylinder.



Mechanical details of screen

A useful procedure is to record simultaneously an upp level by the equi-inclination method and the zero level the anti-equi-inclination method. Comparison of the t halves of the film, with due allowance for Lorentz a polarization factors(1, 2) and for distortion of the upper-le reflexions,(3) gives the required scale factor.

The design of such a screen, although straightforward, w vary with the specific application. The one shown w designed for use with the integrating Weissenberg goniome of Wiebenga, manufactured by Nonius, Delft. The intenti was to record the upper-level reflexions on the lower half the film; these reflexions are contracted, and are more suitab for integration. If integrating techniques had not be available, it would have been preferable to record upper-lev reflexions on the upper half of the film; the reflexions wou then be extended, and more easily corrected for distortion.

Other applications suggest themselves. For example, determining the absolute configuration of a molecule by t methods of Bijvoet and his co-workers, it might be necessa to compare the intensities of reflexions in two symmetricall related upper levels, such as $(h1l)$ and $(h\bar{1}l)$. These lev could be recorded simultaneously by the normal-bea method; corresponding reflexions on the two levels wou be geometrically identical—either both extended or bo contracted—and precise comparison would be facilitated.

REFERENCES

(1) Cochran, W. *J. Sci. Instrum.*, **25**, p. 253 (1948).
(2) Kartha, G. *Acta Cryst.*, **5**, p. 549 (1952).
(3) Phillips, D. C. *Acta Cryst.*, **7**, p. 746 (1954).

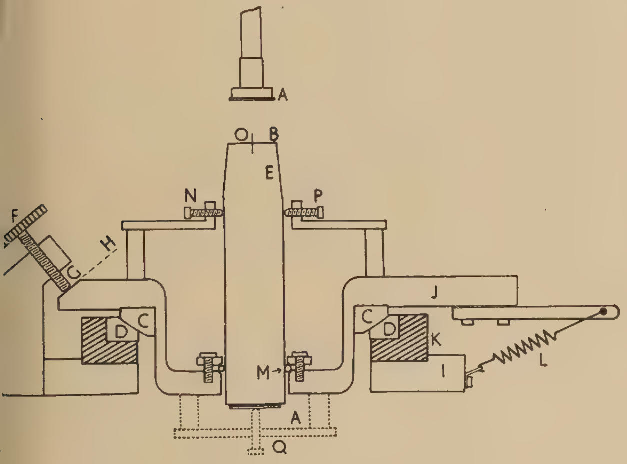
An alternative to gimbals for an ultrasonic interferometer

By A. N. HUNTER, B.Sc., Ph.D., A.Inst.P., Department of Physics, The University of Leicester

[*Note first received* 12 *October*, 1955, *and in final form* 12 *February*, 1958]

ı apparatus for ultrasonic measurements in liquids at quencies of tens of megacycles per second has been signed in this laboratory and has been in use for some ars. The apparatus uses a novel method for adjustment the parallelism of the source and receiver crystals.

The apparatus consists essentially of the fused quartz bar which acts as an acoustic delay line, and two *X*-cut cular quartz crystal plates *A* and *A*′. *E* has optically plane rallel end faces and *A*′ is cemented to the lower face ilst *A* is soldered to a holder which may be moved up and wn by means of a micrometer screw. The experimental uid is contained in a glass cell which fits on the upper end *E* by means of a ground taper joint which is co-axial with quartz bar. In setting up the apparatus it is necessary adjust *A* and *A*′ to be co-axial and parallel. The degree which the co-axial adjustment is important is reduced by aking the active area of *A* larger than the beam of sound om *A*′; thus within the limits of normal adjustments the hole of the beam is effective in exciting *A*. Final adjustment r parallelism of *A* and *A*′ is critical because of the very iort wavelength of sound in liquids at these frequencies (of ie order of 0·02 mm) and this is made acoustically by cating the position of maximum signal strength as the ystals are tilted relative to one another.



Section through base of interferometer

Since the signal strength is also sensitive to mean distance etween *A* and the upper face *B* of *E* it is preferable to keep is mean distance constant during the adjustment; i.e. the ce *B* should be tilted about the point *O* at which the axis *A*′ cuts it. This adjustment could be made by means of mbals but this was found to be inconvenient for the follow-g reason. Gimbals must be mounted in the plane of *B* it in order to maintain the experimental liquid at constant mperature within the required limits it was necessary to iclose the experimental vessel, together with the quartz ir *E*, in a large bath of stirred oil thermostatically con-olled. Thus if gimbals are used they must be either included in the oil bath, when they are difficult of access for adjustment, or be so large as to include the whole oil bath itself. The device described is a neater solution to this problem.

The device consists of two parts *C* and *D* from a standard self-alining ball-race housing: these parts have spherical surfaces with common nominal radius of 6 in. and centre at *O*. In the particular design used *D* is pressed into a ring *K* made of Mycalex in order to provide for thermal insulation from the cast iron base plate *I*. The inner part *C* carries an aluminium casting *J* which forms the base of the oil bath. The quartz bar *E* is held at the bottom in a Neoprene O-ring *M* which makes an oil tight seal with *J* and leaves the crystal *A*′ accessible from below the bath. The upper end of *E* is adjusted and clamped by four screws in a brass ring which is attached to supporting pillars fastened to the base plate *I*: *N* and *P* are the two screws in the plane of the drawing.

The whole oil bath and lower half of the interferometer is tilted in the plane of the drawing by means of the screw *F* working against a spring *L*: the seating *G* against which the screw bears is part of a radius *GH* of the spherical surfaces. It follows that if *O* lies both at the centre of curvature of the spherical surfaces and on the axis of *A*′ the screw *F* will give the required adjustment in this plane. A second screw and spring in a perpendicular plane gives the corresponding adjustment at right-angles to the plane of the drawing.

In order to set up the apparatus a cylindrical metal bar, of the same diameter as the fused quartz bar, is machined to a fine point on the axis at one end and substituted for the quartz bar *E*. The length of this test bar from the point to the plane end is made equal to that of the quartz bar. A temporary bridge piece is attached to the under side of *I* and carries a screw upon which the bar rests: this indicated in dotted lines at *Q* on the diagram. Two travelling microscopes are arranged with their axes horizontal and approximately in vertical planes passing through the two main adjusting screws and the axis of the system: the four adjusting screws locating the top of the bar are also approximately in these two vertical planes. The vertical position of the bar is adjusted by means of the screw at *Q* until rocking the apparatus on the spherical seating shows a minimum of horizontal movement of the point. The four upper screws are then adjusted until a similar rocking movement gives a minimum of vertical movement of the point. Successive repetition of these adjustments results in the point remaining stationary to within 0·02 mm for a total movement of about 0·1 rad on the spherical seating. The axis of the upper crystal *A* is arranged to pass through *O* by means of a second test bar adjusted so that its point touches that of the first bar: this adjustment is not critical because of the larger area of crystal *A*. After these adjustments have been made the fused quartz rod and upper crystal holders are substituted for the test bars. In order to substitute the quartz bar for the metal test bar two only of the four clamping screws at the top are slackened, the quartz bar is then placed in position resting on the screw at *Q* and lightly clamped at the top by retightening the same two screws. The bridge piece at *Q* is then removed and the lower crystal *A*′ is located centrally on the quartz bar *E* by means of a jig.

It is believed that this device may be adapted to other applications and that with optical finishing of the spherical surfaces, and use of the concave seating as a concave mirror for location of the centre of curvature, it lends itself to a high degree of precision.

Vacuum or low-pressure seal utilizing modified standard refrigeration-type, flare tube fittings

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[*Note first received* 25 *March, and in final form* 11 *November*, 1957]

Apart from their wide use in normal refrigeration work, standard refrigeration-type flare tube fittings are used considerably in general industrial applications, more frequently perhaps than any other tube fitting system. This is due to their simpler installation characteristics. Their misalinement tolerance is larger, the component parts are fewer and they are, in some places, much easier to obtain. The main disadvantages of the flare-type tube fittings are also common to the similar compression fittings. They are: (i) development of leakage when the soft metal at the seal "flows" as a result of vibration or thermal expansion and contraction; and (ii) rapid deterioration in the condition of the tube flare after repeated assembling and tightening.

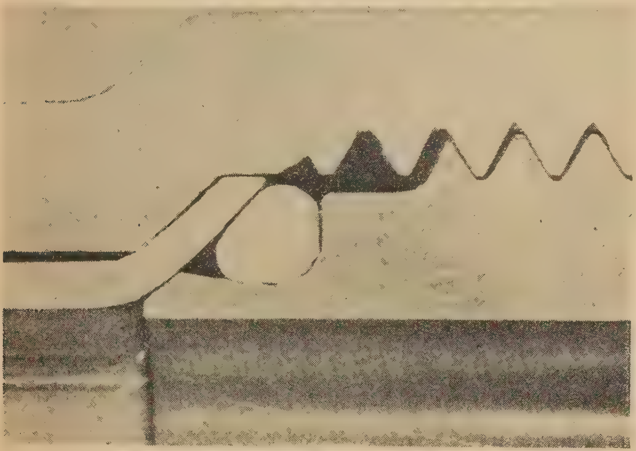

Fig. 1. Enlarged photograph of an actual seal sectioned to show the modification and the amount of O-ring squeeze between the tube flare and fitting

The seal described uses refrigeration-type flare tube fittings with a simple modification to extend their advantages and eliminate their disadvantages. The modification (Fig. 1) comprises a groove machined in the flare fittings to retain standard neoprene O-ring packings. The tube flare is then screwed up to touch the flare fitting. The O-ring is compressed in the groove and the seal made.

This sealing system is not only of value for vacuum pipe work but is also suitable for pressure sealing. Since the O-ring is subject to extrusion on pressure sealing, as is obvious from Fig. 1, the system is not recommended for pressures over 1000 lb/in.^{2} One of the main attractions the modified flare fitting system is that hand tightening all that is necessary to effect the seal. This feature is es cially suitable for laboratory vacuum and pressure wo where repeated connexions have to be made.

Four sizes of standard S.A.E. refrigeration-type fitti have been modified, namely $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$ and $\frac{5}{8}$ in. The dimensio for machining are given in the accompanying table which used in conjunction with Fig. 2. It is important that t grooves are machined to the specified dimensions as othe wise maximum efficiency of the seal would not be attain and the section at the seal might be severely weakened. T grooves are designed to provide the recommended diamet squeeze for a static O-ring seal. The appropriate O-ring si is given in the table.

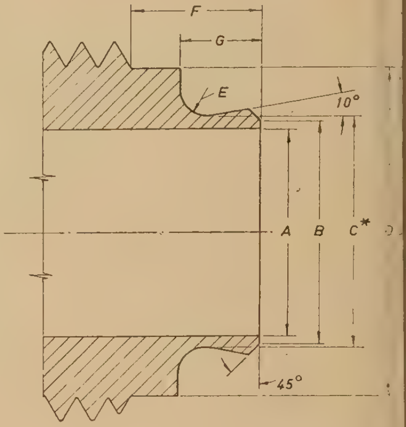

Fig. 2. Dimensions for tube fitting modification (Refer to table in text)

* Feed lathe tool in *H* from standard S.A.E. basic clearance *D* to give bottom groove diameter *C*. O-ring size; B.S.S. 1806: 1951 or A.N. 6227 series. Seal *K* in table in text.

Dimensions *A*, *B*, *D* and *F* are S.A.E. standard and ma vary ±0·010 in. Selection is advisable for fittings as clo to the tabled sizes as possible.

The machining operation is best accomplished by pressin the fitting bore, by hand, over a short mandrel and plungin a formed tool to the required depth. Since the fitting bo may vary, the position of the fitting on the mandrel will va accordingly. A register stop clamped to the formed tool tool post to line up the tool from the tip of the fitting wou therefore assist when machining a batch.

If spanners are to be used in coupling up, the units shou be only lightly nipped. If tightened excessively distortion the seal mounting section may occur, the seal may be affecte and the flow through the system restricted. The seal intended to be hand tightened and this is ample.

In pipe layouts good lining up of the mating flares w naturally give best results. Where the seal is subject working temperatures in excess of 100° C (up to 260° C polytetrafluoroethylene ("Fluon" or "Teflon") rings hav been successfully employed.

Acknowledgement is extended to Mr. A. Yates for assistanc with the groove dimensioning.

Relevant dimensions and details for flare fitting modification

O-ring size; B.S.S. 1806: 1951 *or A.N.*6227 *series. Seal No. given under K*

size	Diameter (in.)				Radius (in.)				
(in.)	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*K*
$\frac{1}{4}$	3/16	7/32	0·236	0·344	1/32	5/32	0·100	0·054	4
$\frac{3}{8}$	9/32	5/16	0·387	0·531	1/32	7/32	0·130	0·072	7
$\frac{1}{2}$	13/32	7/16	0·455	0·641	3/64	1/4	0·157	0·093	9
$\frac{5}{8}$	1/2	17/32	0·572	0·750	3/64	9/32	0·168	0·089	11

An electrode cutter and modified arc stand for spectrochemical analysis

By J. McAndrew, Ph.D., F.G.S., Commonwealth Scientific and Industrial Research Organization, University of Melbourne, Australia

[*Note received* 29 *July*, 1957]

he interest shown by visitors to this laboratory in a simple ut efficient cutter for carbon electrodes and in modifications) an arc and spark stand (by Hilger and Watts Ltd.) have rompted the publication of details of these devices.

The electrode cutter. Carbon electrodes are usually cut n a modified lathe or with a cutting head mounted on the aft of an electric motor. Scott and Fraser(1) and Slatter nd Stitch(2) have recently described modified lathes in hich a stationary cutter is fed against the rotating carbon od; the greater rigidity of this arrangement is preferred by e former for shaping deep, thin-walled cavities.

In the present electrode cutter, carbon rod is fed into a otating cutter mounted on the shaft of an electric motor.

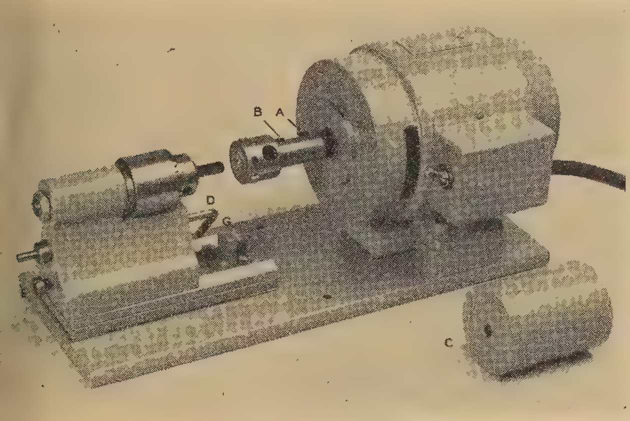

Fig. 1. The electrode cutter

niform narrow electrodes with thin-walled, deep cavities re rapidly produced in quantity from $\frac{1}{4}$ in. carbon rod, as he cutter has ample rigidity. The cutter is less expensive han those based on a lathe, and a shield allows it to be sed in any reasonably clean laboratory.

The cutter (Fig. 1) has a cutting head fitted on the shaft f a $\frac{1}{12}$ h.p., 2800 rev/min, B.B. single-phase, squirrel cage nduction motor, and held in position by a socket-head grub crew *A*. Three cutters of $\frac{3}{16}$ in. square high-speed steel are nounted in slots at the front of the cutting head and retained n position by grub screws. One cutter has been found ufficient to reduce a 6 mm diameter carbon rod to 2 mm liameter; however, smoother cutting action is obtained from hree cutters set to reduce the rod in successive steps. The lectrode cavity is bored by a drill mounted on a $\frac{1}{4}$ in. shank nd held in a $\frac{1}{4}$ in. hole along the centre of the cutter by a exagonal socket grub screw *B*. Two $\frac{3}{8}$ in. holes on opposite ides of the cutting head immediately behind the cutters rovide ample outlet for the carbon powder. This powder s retained in the metal cylinder *C*, which fits over the cutting ead on to the shoulder at the front of the motor. The rod nters through a $\frac{5}{32}$ in. hole in the front of the cylinder.

The carbon rod is held in $\frac{1}{4}$ in. Jacobs chuck, mounted on cast iron holder which slides along a double V-bed. The -tracks are screwed to a metal plate alined on shims at each end, so that the chuck is coaxial with the cutter, and held on the base-plate in this position by a screw at each end.

In operation, the electrode holder is easily moved by hand smoothly and rigidly, provided a slight downwards pressure is maintained. The depth of the boring is controlled by the adjustable stops *D* and *E*. The carbon rod is positioned in the chuck with its front end level with the front of the stop *D*, which is swung upwards for this setting. The stop *E* is a threaded rod which protrudes through the front of the metal block and is set to stop the forward movement by coming against the bar *G*, at the desired depth of boring.

The cutting head and sliding motion of this apparatus are sufficiently rigid for the routine production, from $\frac{1}{4}$ in. carbon rod, of uniform electrodes which have an 8 mm deep cavity 1·3 mm in diameter, and a wall thickness of 0·3 mm. It is easily adjusted to cut electrodes of other dimensions; for example, the cutter is also used to produce carbon electrodes for cathode layer analysis which have a cavity 8 mm deep, of bore 0·8 mm and external diameter 2·8 mm,(3) and the frequently used electrode with a similar cavity and an external diameter of 3·00 mm is readily produced. The cylindrical shield *C* effectively catches the carbon powder produced, and also protects the cutting head from contamination, enabling the cutter to be used in any reasonably clean laboratory without interfering with adjacent equipment.

Modified Hilger arc stand. A Hilger arc and spark stand has been modified to give convenient operation of the arc, improve the electrode holders, and reduce to a minimum the length of electrode necessary. The improved stand is shown in Fig. 2.

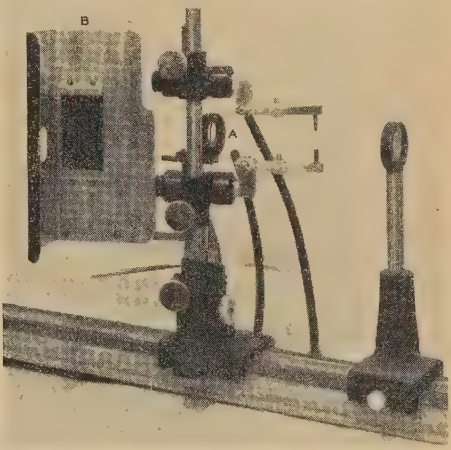

Fig. 2. The modified arc and spark stand (by Hilger and Watts Ltd.)

The modifications to the stand comprise:

(i) the base which holds the stand on the optical bench has been reversed to bring the main column and electrode centring adjustments to the same side of the optical bench as the operator;

(ii) the lens *A* which projects an image of the arc to the rear has been replaced by one of slightly longer focal length, and has been mounted on an adjustable slide at the top of the $\frac{3}{4}$ in. column, which has been set back $1\frac{1}{2}$ in. by an S-curve in the column. This permits the electrode holders to come together without fouling on the lens. A much enlarged image of the arc is projected on to a board at the rear, facilitating observation and adjustment of the electrodes during arcing. (To show this lens clearly on Fig. 2 it has been moved to the right of the operating position.)

(iii) stainless steel electrode clamps of the type described by Churchill[(4)] have been installed. A coil spring at the rear of the pivot clamps the electrodes with a force of about 3 lb. The electrode holders are clamped by wing nuts to metal blocks which offset each electrode holder 1¼ in. towards the other from the position of the original electrode holders. This allows the use of carbon electrodes only 1 in. long, thus producing a substantial saving in carbon;

(iv) a pivoting shield *B* has been installed which swings to the left to the position shown in Fig. 2 for changing electrodes. Before arcing this shield is swung to the right against a stop, and protects the operator from the arc, while allowing direct viewing of it through a deep violet filter.

ACKNOWLEDGEMENTS

The components of this equipment were constructed and installed by A. J. Wilcock, and by S. T. Engineering, both of Melbourne. The photographs are by Mr. R. Oldfield. Drs. A. B. Edwards and J. V. Sanders have kindly critically read the manuscript.

REFERENCES

(1) Scott, R. D., and Fraser, A. M. *Spectrochimica Acta*, **5**, p. 422 (1953).
(2) Slatter, A. V., and Stitch, S. R. *Chem. and Industr.*, p. 567 (1956).
(3) Mitchell, R. G. *Commonwealth Bureau of Soil Science Tech. Comm.*, **44**, p. 79 (1948).
(4) Churchill, J. R. *Selected topics in modern instrumental analysis.* Chap. 5. Ed. D. F. Boltz (New York: Prentice-Hall Inc., 1952).

A high vacuum valve

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Bucarest, Magurele, Rumania

[*Note first received* 19 *August, and in final form* 20 *December*, 1957]

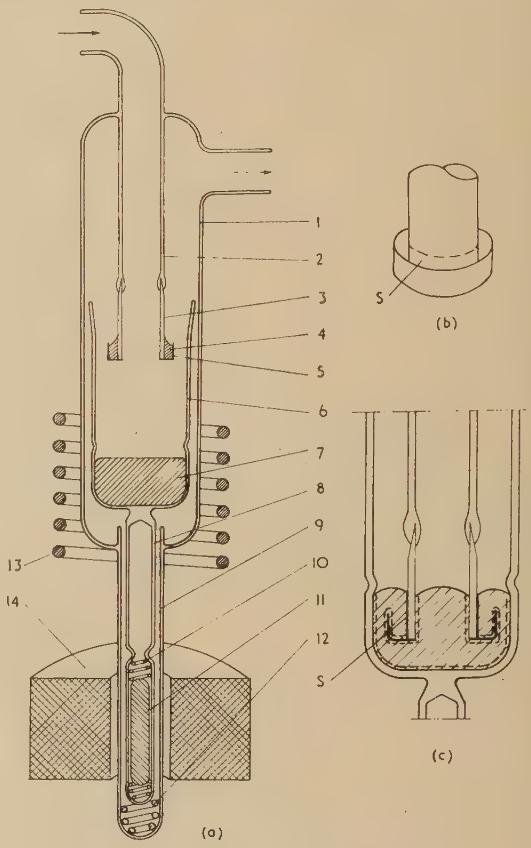
The valve described uses tin, first molten and then solidified, as tightening element. The possibility of a valve with tin has been pointed out by Yarwood.[(1)] A tin valve with a contact surface glass–tin has been described by Tretyakov.[(2)] In our construction there is no need to use spectroscopically pure tin and the possible formation of tin oxide is of no importance.

The body of the valve is a molybdenum glass tube [Fig. 1(*a*)] which has a narrowed end 9 within which another glass tube 8 closed at both ends and attached to a Pyrex glass cup 6 containing some tin 7 can slide easily. In the inner part of this latter tube, at its lower end, an iron cylinder 11 is placed between two non-magnetic helical springs 10. To avoid mechanical shocks, a helical spring 12 made of tungsten wire is placed in the guiding tube. A Kovar tube 3 is sealed to the central glass tube 2. A collar 5 made of tantalum foil is soldered electrically to the Kovar tube forming a circular groove [Fig. 1(*b*)], which is filled with tin 4.

Tin melting and outgasing of all metal parts is done with the h.f. coil 13. The vertical movement of the cup is obtained by magnetic action of a d.c. coil 14 on the iron cylinder.

To close the valve, the cup must be raised until the tantalum collar is entirely immersed in the mass of molten tin [Fig. 1(*c*)] and kept there until solidification. To open the valve, the tin is melted again and the cup is lower carefully.

The tantalum collar is filled with tin by plunging it in t molten metal; the contact surface *s* [Fig. 1(*b*)] Kovar-t must be previously cleaned by polishing it with sand-pap and wetted with scouring substance, e.g. diluted hydrochlor acid. In this way the Kovar tube is tinned, which is essential condition, as we could observe that a conta Kovar-tin, established directly *in vacuo*, is not gas-tight; th tantalum collar filled with tin prevents the Kovar tube fro losing its tin during the opening of the valve. Tantalum w chosen because it did not alloy with tin at workin temperatures.



Details of high vacuum valve

In Fig. 1(*c*) the un-wetted tin contact surfaces are dotte To prevent the gas molecules passing from one part to th other, it is only necessary to ensure the tightness of th contact surface between the Kovar and the tin [*s*, Fig. 1(*c*) This is achieved by tinning the Kovar tube as mentione above.

To ensure the tightness of the valve, the diameter of th tin-filled cup, the free motion of the cup inside the valv and the amount of metal in the cup, must be so determine that on closing the valve no contact between the tantalu collar and the inner wall of the glass cup is possible. Th great height of the glass cup and the manner in which th guiding tube is sealed to the body of the valve [Fig. 1(*a* are some means of protection against the little drops of ti which fall out of the cup during the outgasing and ma block the motion of the cup. Fig. 1(*a*) shows two littl hollows made in the glass cup in order to avoid the cu separating from the tin after the closing of the valve.

With this vacuum valve it was possible to maintain a ayard–Alpert manometer at a pressure of 5×10^{-8} mm of ercury. During repeated tests of 50 hours duration each, o noticeable leakage against air at atmospheric pressure ould be detected.

REFERENCES

) YARWOOD, J. *Vacuum*, **3**, p. 398 (1953).

2) TRETYAKOV, I. I. *Zavodskaya Lab.*, **22**, p. 362 (1956).

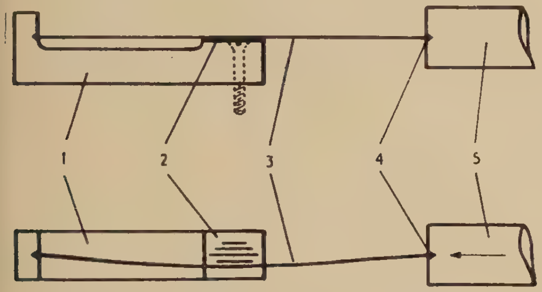
A simple expansion indicator

By A. L. SIMS, Physiology Institute, University College, Cardiff

[*Note received* 5 *November*, 1957]

is of advantage when using a thermal advance ultraicrotome to obtain an indication of the amount of thermal xpansion, and a simple method by which this may be done described in this note.

A hardened steel wire is arranged (see figure) so that it an be compressed longitudinally between the end of the dvance bar and a fixed angle bracket. As the bar advances, nd the distance between the bar and bracket decreases, the ire bends. The amount of curvature of the wire, which can e measured against a scale, is related to the degree of thermal xpansion. To prevent the bent wire rotating, a small platorm is placed in contact with the wire before heat is applied o the advance bar and to stop the wire from indenting the aterials at either end it is housed in conical watch bearings, hese are set in the end face of the advance bar and the racket face respectively, thus the wire can be easily removed hen not required.



Elevation and plan view of indicator

1, Nilo 40 angle bracket; 2, white Perspex scale; 3, pivot steel wire, 30 s.w.g. 4 in. long; 4, Kelton end bearings; 5, 65/35 brass advance bar.

Note on a protective device for thermal converters

By A. G. MUNGALL, Ph.D., and I. ABELLA, B.A., Division of Applied Physics, National Research Council, Ottawa, Canada

[*Note received* 4 *December*, 1957]

he accuracy of measurement of alternating and direct urrents by thermal converters depends on the magnitude of e thermal e.m.f. developed by the thermojunction.* Conequently, these instruments are usually operated at currents p to 70% of the burn-out value. Small overloads can erefore lead to failure of the instrument. We have in use simple electromechanical device which interrupts the heater rcuit of the converter when the thermal e.m.f. reaches a point corresponding to heater currents of 80–90% of the burn-out value. The device protects the instrument against suddenly applied a.c. and d.c. overloads up to ten times the burn-out value.

Fig. 1 shows a typical basic circuit in which a thermal converter is used as a current measuring instrument. The thermal e.m.f. is a precise measure of the average current, a.c. or d.c., flowing through the heater. The protective device is placed across the thermojunction terminals, and the switch which it operates is inserted at *S* in the heater-load circuit.

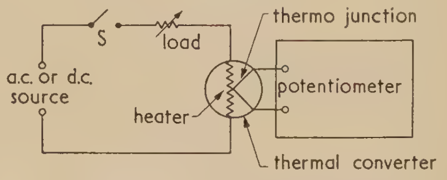


Fig. 1. Typical use of a thermal converter in current measurement

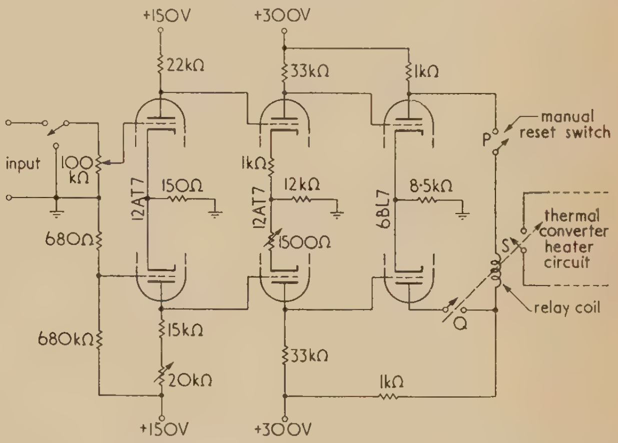


Fig. 2. Balanced amplifier used in the protective device

The device consists of a three-stage balanced d.c. amplifier (Fig. 2) which amplifies the thermal e.m.f. The output developed across the plates of the final stage is placed across a relay coil. The gain and zero are adjusted so that when the thermal e.m.f. attains the desired limiting value (7 to 9 mV in the converter used), the output is sufficient to operate the relay, breaking the heater circuit at *S*. Simultaneously, a second pair of contacts operated by the relay breaks the plate circuit of the balancing half of the last stage at *Q*. Sufficient current through the other half of the tube is then maintained flowing through the relay coil, even with no input signal to the amplifier, to operate the relay and prevent further overloading of the thermal converter. The relay is reset manually by opening the plate circuit of the final stage at *P* after the overload has been removed.

Operating the device from the thermal e.m.f. has the advantage that protection is provided for both alternating and direct currents flowing in the heater. The maximum overload for which the thermal converter is protected is controlled by the amplifier gain, the relay response time, and the thermal time lag between heater and thermojunction. The amplifier gain and zero determine the thermal e.m.f. at which the heater circuit opens for a gradually applied overload. For sudden overloads, the heater wire may fuse before the relay can break the circuit, and occasionally the thermocouple can fuse after the relay opens because of continued heating of the junction.

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* HERMACH, F. L. *J. Res. Nat. Bur. Stand.*, **48**, p. 2 (1952).

NOTES AND NEWS

Correspondence

A narrow-band optical filter to isolate the 4245 Å spectral region

For the determination of uranium isotopic abundances by high resolution emission spectroscopy it was necessary to construct an optical filter to eliminate interference from overlapping orders of an echelle grating whose free spectral range at 4245 Å in the fourteenth order was several hundred angstroms. The absorption of thin films of silver makes it extremely difficult to produce a "silver-dielectric-silver" interference filter having a half-width of less than 100 Å and a transmission in excess of 30%. However, by constructing all dielectric, quarter-wave stacks it is possible to produce filters with a half-width of 60 Å and transmissions of greater than 80%, but an unfortunate characteristic of this type of filter is the appearance of side bands, due to the decrease in reflectivity of the dielectric stacks at wavelengths other than that for which they were constructed. The elimination of the sidebands was achieved by means of the composite filter described in the following paragraphs.

A dielectric interference filter composed of two stacks consisting of five alternate quarter-wave layers of zinc sulphide and cryolite and separated by a second-order spacer of cryolite, was constructed on a thin glass substrate using the vacuum deposition and monitoring systems of Lissberger and Ring.* To protect the dielectric layers a cover glass was cemented over them by means of crystic 191 resin (by Scott-Bader & Co. Ltd.). Set in this resin the layers were unaffected by temperature change, humidity and shock. Since suitable filter glasses were not obtainable, side bands were eliminated by two solutions:

(*a*) Saturated sodium nitrite solution to cut off below 3900 Å.

(*b*) Freshly prepared cuprammonium sulphate solution diluted to cut off at approximately 5000 Å.

To fabricate the complete filter a Pyrex glass ring 2 in. diameter × $\frac{3}{8}$ in. deep × $\frac{1}{16}$ in. wall was cut from a length tube and its ends ground flat and parallel to each other. thin glass disk was cemented inside the ring, by means Araldite 101 (by Aero Research Ltd.), in such a position th one component cell was $\frac{1}{16}$ in. deep. Two small notch were cut in the outer edges of the ring and end plates cement on. One end of the cell was sealed with a glass disk and t other end with the dielectric interference filter. The outsi surfaces of the filter had been bloomed for maximum trar mission. Sodium nitrite solution was injected through notch into the $\frac{1}{16}$ in. cell by means of a hydodermic neec and the hole sealed. The other compartment was filled in similar manner with cuprammonium sulphate. The comple filter is shown diagrammatically in Fig. 1. The charac istics of the filter, measured on a Uvispek spectrophotomet (by Hilger and Watts Ltd.), were a half-width of 75 Å and transmission of 66% at 4245 Å. A full transmission cur is shown in Fig. 2.

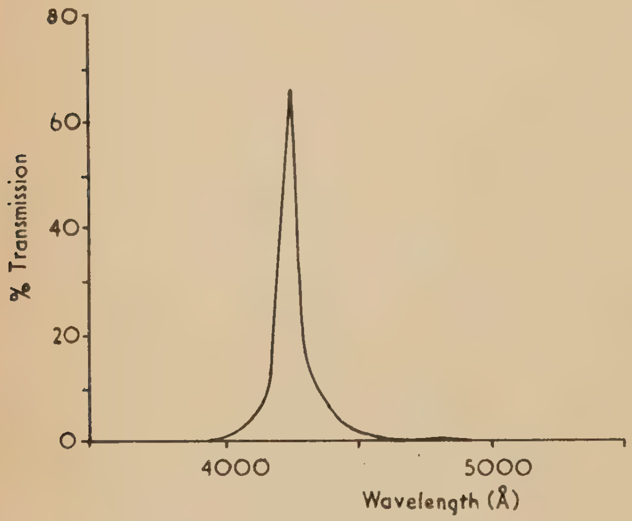

Fig. 1. Section of filter cell unit

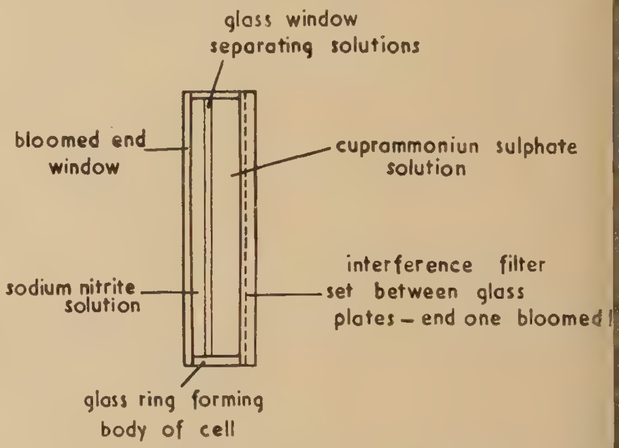

Fig. 2. Transmission of filter cell. Peak transmission 66%; half-width 75 Å

Acknowledgements are made to Professor S. Devons f permission to use the vacuum deposition and monitorir equipment at the University of Manchester, for the construction of the dielectric multi-layers, and to the Managir Director of the Industrial Group of the U.K.A.E.A. fo permission to publish this note.

Chemical Services Department,
United Kingdom Atomic Energy Authority,
Capenhurst Works,
Capenhurst, Cheshire.

R. P. Thorne
R. F. Warren

[20 February, 195

Chart calibration of a photographic recording microphotometer

In the description by Bor† of a photographic recording micro photometer, it is implicit that abscissa markers are put on t the photographic paper by sweeping the spot imaged by th galvanometer, either before or after recording, with th drum stationary.

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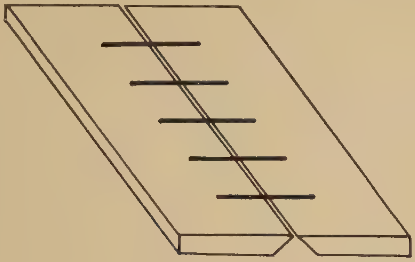
* Lissberger, P. H., and Ring, J. *Optica Acta*, **2**, p. 42 (1955).

† Bor, J. *J. Sci. Instrum.*, **34**, p. 140 (1957).

Confronted with the same problem of converting a manual crophotometer (by Hilger and Watts Ltd.) to photographic cording, I used a system giving a continuous marking of e photographic paper with ordinates and abscissae, while cording was in progress. In front of the drum bearing the per, a screen with a slit parallel to the axis of the drum



The masking slit and wires, viewed from the side of the recording drum

is mounted. One form of this screen is shown in the ure. The slit is at least as long as the recording drum, d has a width of the order of $\frac{1}{2}$ mm. A series of wires are ed across the slit at known positions. The galvanometer rms a slit image lying in the plane of this slit, and perpencular to it. Just below the galvanometer a small lamp is ounted. The radiance of this lamp is adjusted until the photographic paper is fogged to a grey when the drum is rotated at the recording speed. A contact breaker on one of the shafts driving the drum switches this light off a fixed number of times per revolution of the drum. Thus, in operation, the fogging light traces shadows of the wires circumferentially; at each interruption, an unfogged line is left perpendicular to these circumferential shadows. The abscissae put on the paper are independent of the speed of the driving motor, since they are linked mechanically to the plate traverse. Further, any twist or rumple of the paper on the drum is compensated by using this simultaneous system of marking the paper. Since the galvanometer is forming a slit image, small displacements of the image perpendicular to the axis of the drum have no effect on the recording. This simplifies the elimination of vibration in the instrument.

At the Imperial College (Technical Optics Section), where this device was built, a slightly different arrangement was used. The long slit was replaced by the shadow of a wire stretched across a piece of plate glass, subsequently aluminized. The transverse wire markers were replaced by acid-etched lines in the surface of the plate glass.

I.G.Y. Station,
Department of Scientific and
Industrial Research,
Invercargill,
New Zealand.

M. GADSDEN
[16 December, 1957]

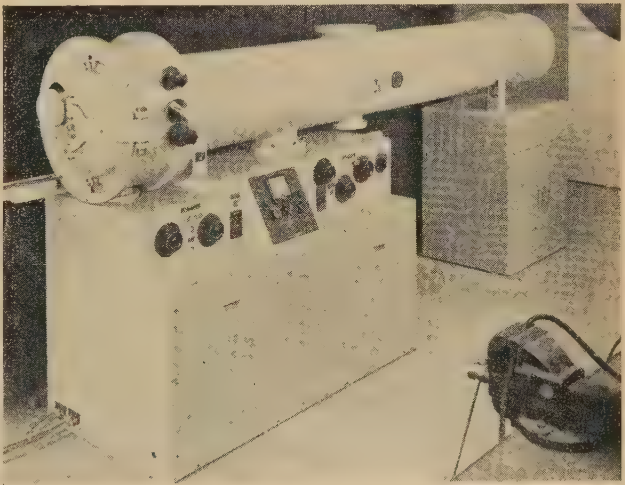
New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

acuum spectrograph with three metre grating. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

grating used at approximately normal incidence confers any advantages on a spectrograph if wavelengths below out 400 Å are not to be recorded. Its astigmatism is much ss than that of a grating at grazing incidence, its effective erture is greater, and on both accounts it allows far shorter posures. A normal-incidence grating, with 3 m radius of rvature, is used in this vacuum spectrograph. The camera n be isolated by a flap valve from the rest of the instrument, that plates can be changed without breaking the vacuum the main casing. The dispersion is almost constant bout 6 Å/mm in the first order) throughout the spectrum, d adjustments are not critical. The instrument has been signed with a view to future supplementation by photoectric recording.

All controls are external and are provided with dials giving clear indication of their setting. There is a control for cking the plate so that successive spectra up to 6 mm wide n be photographed without opening the instrument, another r adjusting a metal screen that has the effect of a Hartmann aphragm with three apertures 2 mm high, another for ljusting the width of the slit to a maximum of 2 mm, and a urth for selecting the wavelength range. The shortest avelength that the spectrograph can record is about 400 Å d the longest about 2900 Å. The plate size is 10 × 2 in. he light source can be sealed to the spectrograph by means an O-ring seal. Gas leakage from the source is reduced far as possible by a secondary, fixed, slit little more than 2 mm wide, but for work on the longer wavelengths a fluorite window can be fitted to provide a perfect seal. If components such as absorption cells with fluorite windows are to be used, they can be supported on the 21 in. accessory bar for which the instrument makes provision.



Vacuum spectrograph with 3 m grating at normal incidence

The instrument stands on two cabinets, one serving as a cupboard and the other housing the pumping equipment.

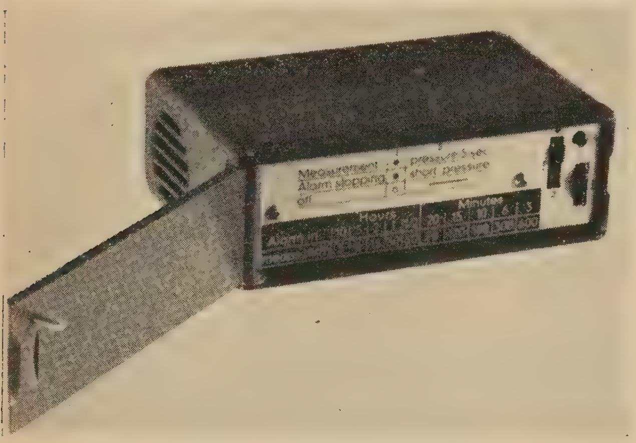
Infra-red transmitting lenses. Servo Corporation of America, 20–20 Jericho Turnpike, New Hyde Park, New York, U.S.A.

These single-element infra-red lenses have been designed to give optimum performance where achromatic imagery is not required. They have minimum spherical aberration when imaging an object at infinity at a wavelength of $3\frac{1}{2}\ \mu$. Reasonably good performance extends from 2 to 5 μ. Good transmission is obtained from 1 to 12 μ. Anti-reflexion coatings are available for any specified wavelength in the 1 to 6 μ range. Focal lengths from 2 to 12 in. are available at relative apertures of $f/2\cdot0$ and $f/4\cdot0$.

Radiation warning instrument for X-ray and γ-ray workers. Radiatron, 7 Sheen Park, Richmond, Surrey.

An ionization chamber type radiation warning device, the P.T.W. Monitor, has been designed which gives a loud warning signal when the accumulated X-ray or γ-ray dose reaches 30 mr. The instrument is a battery-operated, pocket type unit weighing $12\frac{1}{2}$ oz. into which headphones may be plugged if required.

The unit can be used as a monitor placed alongside operators working within the range of X-rays or gamma-rays, where the hands are not free or where the attention or skill of the operator cannot be relied on, or where it is intended to expose the worker to a higher than continuous dose rate for a limited period. It may be used as a monitor for non-operational workers in the area, as the dose of 30 mr corresponds to the maximum weekly dose now allowed for such workers, and is about half the present daily maximum permissible dose for a worker on radioactive work. It is likely that the maximum permissible weekly dose is to be further reduced. Instruments operating on a higher dose than 30 mr can be made for special purposes.



Radiation warning instrument

The warning instrument uses an ionization chamber and has a flat response to radiation energies from under 100 keV to 3 MeV, which is of use in most locations as the radiation is composed of various energies due to Compton scatter.

Every dosemeter is calibrated with its own calibration source. This is a small β-ray source normally housed in its lead-lined container, the surface dose, when closed, being less than $0\cdot6$ mr/h, due mainly to Bremsstrahlung. Placing the source in position on the dosemeter, the correct operation of the instrument can be checked with a stopwatch against a calibration sheet supplied with each Monitor. In weak radiation fields it is possible to measure a partial dose (less than 30 mr). This is done by exposing the dosemeter fi to the radiation to be measured for an arbitrary time t_1 a then to the calibration source. If the warning signal sou after an additional time interval t_2 and if the calibration ti is t_c, the partial dose received during the time t_1 is th $30(t_c - t_2)/t_c$ mr. The dose rate can be calculated from time taken for 30 mr or for the partial dose t_1.

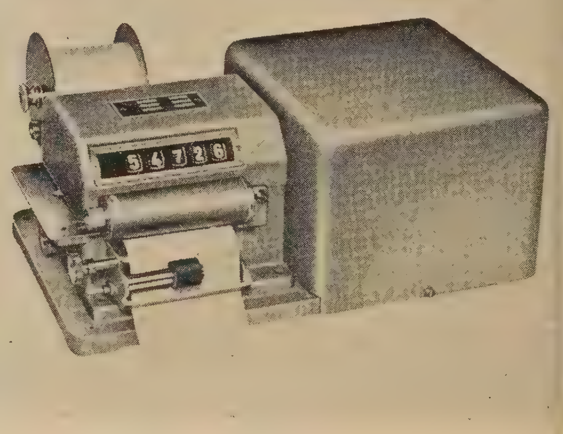
The instrument is battery-operated, having rechargea batteries with a capacity of 220 mAh. Since the batter are only discharged during the signal, there being no curr drawn during measurement, one charge is normally suffici for several months. A small mains-operated charging u (weighing a few ounces) is also available that recharges batteries, without removing them from the instrument, means of a miniature plug and socket. The instrument transistor-operated and is suitable for outdoor work moderate climates. It is manufactured by Physikali Technische Werkstätten of Germany.

Digital printing counter. Radiatron, 7 Sheen Park, Richmo Surrey.

The digital printing counter, manufactured by Irion a Vosseler of Germany, has three basic forms. It will co and print electrical impulses up to a speed of 5 per seco elapsed time in $0\cdot01$ minutes or seconds, and revolutions o shaft up to 50 rev/s.

A number having 3–6 digits is printed, together with automatically changed identification number or a har adjusted code. The printing is on a $2\frac{3}{8}$ in. wide paper str all digits being printed simultaneously. Printing, paper sh and resetting are automatic on receipt of a printing impu and the total time taken is one second.

The counter may be used for nuclear particle counti and is often operated through a scaler with a factor of 1



Digital printing counter

to increase counting speed. Due to the smoothing effect the scaler, its paralysis time for random pulses is far shor than the counter dead time ($\frac{1}{5}$ s), divided by the scali factor. For radioactive isotope assay, the printing coun is used in its form of a time printer. It is triggered by pre-determined count scaler when a pre-set number counts are reached. In automatic plant control, the coun may be applied to print any variable or deviation that c be converted into electrical impulses (temperature, pressu c.). On the production line it can be used for batch ounting. The counter may be built into automatic control anels and measuring equipment (the volume is less than × 6 × 6 in.).

urface finish interference microscope. C. Baker Ltd., 244 High Holborn, London, W.C.1.

recent development in surface examination has been troduced based on the principle of interference microscopy. hree advantages are said to arise from the use of a purely ptical system. First, contact with the specimen is avoided, iminating damage and permitting soft materials, paints and e like to be examined. Secondly, a relatively large area of e specimen is under observation. Thirdly, high magnication, together with a readily visible and adjustable fringe attern, permits visual assessment of a surface finish with an ccuracy of the order of ·1 μin. By photomicrography, for hich a 35 mm camera is included in the equipment, finer easurement of surface faults can be readily made.

The work stage is supported on a yoke with suitable amping arrangements. A hemispherical bowl is cast in the oke and carries a mating insert approximately hemispherical form. The upper face has a hardened and lapped surface support the work stage. Positioning of the table is precise, mediate and positive. Tapped holes are provided in the ecimen table to accept small fixtures for parts to be amined.

The optical system is a modification of that devised by irau and is shown in Fig. 1. The objective is designed in ich a way that only one is required instead of the normal ir. Another feature is that the division and recombination the light beam are confined to the small region between e objective lens and the specimen surface. Two versions the objective are used, one for high and one for low power. order to compensate for reflectivity variation between etallic and non-metallic surfaces a second pair of objectives available suitably adjusted to non-metallic surface work. agnifications available under both conditions are ×100 d ×400.

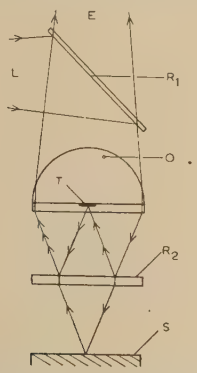


Fig. 1. Surface finish interference microscope. ×40 system

Considering Fig. 1, light, mercury green, from the lamp L projected on to the semi-reflecting surface R_1 whence it is flected into the back of the objective lens O. The objective ns focuses the light upon the surface of the specimen S and uminates it. In passing from the objective lens to the ecimen the light encounters a second semi-reflecting rface R_2 and some light is reflected back so as to illuminate optically-worked, metal-coated reference surface T. Further reflexion from this surface produces its image, coincident with the image of the specimen S.

The reference spot T and the specimen surface S are optically equidistant from R_2. Hence the system provides an effect equivalent to placing the reference surface T in contact with the specimen surface S. An interferometric comparison is thus provided between the reference and the surface. To produce a usable fringe pattern it is necessary to tilt the specimen very slightly relative to the axis of the microscope. It is for this reason that the tilting table is provided.

The function of the low power system, shown in Fig. 2, is precisely the same and the same notation has been applied.

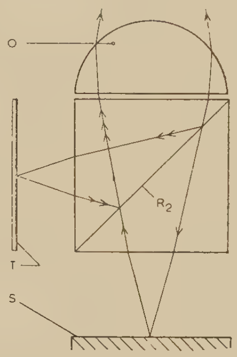


Fig. 2. Surface finish interference microscope. ×10 system

With a little experience, a surface defect made in surface finishing may be visually estimated to about 1 μin.

Examination of plane, cylindrical or spherical surfaces may be directly undertaken. For internal work it has been established that use of the plastic film technique gives results comparable with direct observation.

A new prism for the Uvispek spectrophotometer. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

A synthetic fused silica prism can be supplied for use on all Uvispek spectrophotometers of series number 303 or later. The new prism is said to give a much better ratio between transmitted light and stray light at short wavelength and the effect of stray light at wavelengths of 2000 Å and well below is negligible. By fitting the new prism the range of the instrument is extended down to 1850 Å.

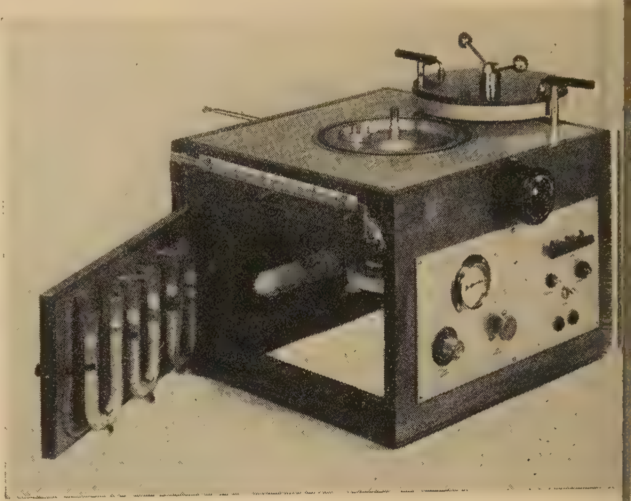
Thermal relays. Mercia Enterprises Ltd., Godiva House, Allesley Old Road, Coventry.

The basic mechanism of the G–V series of relays consists of two members of equal length capable of longitudinal expansion with change of temperature and having identical coefficients of expansion. One of these members is the actuating element of the relay; according to type, it consists of a stainless steel shell with heater embedded, a stainless steel strip with a heater wound round it or a group of nickel alloy wires in tension. The other element is of stainless steel. A simple mechanism multiplies any difference of expansion between the two members so as to move a contact arm in or out of contact. Ambient temperature changes affect the two members equally and cause no motion of the contact arm. Energization of the heater causes expansion of one member only and results in operation of the contact arm. It is claimed that the use of longitudinally expanding members instead of bi-metallic strips greatly improves the resistance to shock and vibration, reduces contact chatter, gives more accurate ambient temperature compensation and reduces the release time. Timing relays of the hot-wire type are available with a basic time between 0·5 and 2·75 s. Ribbon type relays have a basic time between 3 and 12 s, and embedded heater relays a basic time between 12 and 180 s. The heater is rated at 4 W, and with most types is available for voltages between 2·1 and 230 V. The contacts can be either "make" or "break" and are rated at 3 or 6 A 250 V a.c. The relays withstand accelerations up to at least 30 *g* and vibration (55–200 c/s) of at least 10 *g*.

Vacuum oven. Griffin and George Ltd., Ealing Road, Alperton, Wembley, Middlesex.

The Gardner precision vacuum oven was developed for investigations in the drying of such labile products as sugar syrups and molasses. Its use is in determining the loss of weight on heating. The sample is taken into solution and distributed over an aluminium powder extender contained in a sample dish. It is then heated under vacuum, while a current of air or inert gas, dried to a water content not exceeding 0·0007 mg/l., is bled over its surface.

Part of the air bleed drying train can be seen on the door of the cabinet, the U-tubes being filled with activated alumina and the air passing to a horizontal glass tube filled with barium oxide. In the top centre of the case is the cadmium plated mild-steel heating block which can carry six shallow 2 in. diameter sample dishes. The metal lid covering the heating block is $\frac{3}{4}$ in. thick and is thermally insulated on the top. The two halves of the heating chamber are clamp
together by means of a nut on the central spigot. Means
vacuum sealing are provided. Ducts allow the air to p
over the samples and out to a desiccator containi
phosphorus-pentoxide. A bimetallic thermostat in



Vacuum oven

heating block, adjustable up to 110° C ± 1° C is provid
together with a thermometer, soap film flowmeter, vacuu
gauge and vacuum control valves and connectors. Twe
heating elements are symmetrically disposed in the heati
block and two loadings of 70 and 160 W may be selected.

New books

Engineering precision measurements. 3rd ed. By A. W. JUDGE. (London: Chapman and Hall Ltd., 1957.) Pp. vii + 447. Price 65*s*.

This book, first published in 1944, has now reached its third edition in revised form with the addition of chapters dealing with slip gauges, straightness and flatness measurements, interferometry and surface finish. The author states in the preface that the book is biased towards the practical applications of measurement. Even so, it is disappointing to find so much space devoted to descriptions of measuring instruments rather than to principles of measurement. In a number of places the clarity of expression leaves much to be desired. It is difficult to understand what the author means, for example, by the statement "different degrees of linear magnification up to those corresponding with wavelengths of light can be employed." The terminology used is sometimes incorrect and does not always conform with that recommended in B.S. 2517: 1954, *Definitions for use in mechanical engineering*.

The book contains a number of errors, and, rather surprisingly in view of the fact that it has been revised, some out-of-date information. A most noticeable error is that a photograph illustrating a drunken thread testing machine is described as a plain screw pitch measuring machine and *vice versa*.

Bearing in mind the above criticisms I would not recommend this book to a student. L. W. NICKOLS

Technology of instrumentation. By E. B. PEARSON. (Londo
English Universities Press, 1957.) Pp. xv + 2
Price 25*s*.

Professor Pearson is to be congratulated on having fille
serious gap in the literature of instrumentation with a bo
which can be read with profit by the general reader. Mode
instrumentation with its feed-back systems is a complicat
study. The beginner can do no better than to read Profess
Pearson's admirably presented introduction.

The scheme of the book is clearly set forth in the chap
headings: Basic principles of measurement; Basic charact
istics of measuring instruments with a moving element; T
dynamic accuracy of an instrument; Laboratory techniq
for measuring the response characteristics of instrume
movements and simple servomechanisms; Instrumentati
applied to process control; Improvement of servomechani
performance; Stability criteria for linear servomechanism
Components used in servomechanism layouts and instr
mentation of mathematics. The student is led logically fr
basic principles to their application in complex equipme
and much of the jargon associated with closed-loop cont
systems is either explained or made unnecessary.

At a time when instrumentation is becoming a ma
preoccupation of the industrialist and when the want of we
informed instrument technologists is being felt on all sid
Professor Pearson's book should be of considerable nation
value. J. THOMSON

lectronic analog computers. 2nd ed. By G. A. and T. M. Korn. (New York: McGraw-Hill Book Co. Inc.; London: McGraw-Hill Publishing Co. Ltd., 1957.) Pp. xiv + 452. Price 56*s*. 6*d*.

his book is concerned with a particular class of analogue omputers, namely those using direct current representation variables. A good description and explanation of the stems employed is given in Chapters 4, 5 and 6, and overall esign is reviewed in Chapter 8. A discussion is given in e Introduction of analogue versus digital computers which notably moderate in tone. The authors rightly point out e advantages in speed offered by special purpose techniques d point to the possibilities of substituting actual equipment an analogue system in place of the electronic model used design study. On the other hand they recognize the nitations in accuracy and flexibility of analogue systems. hey have failed, however, to convince me that present-day gineers would find any more difficulty in reformulating oblems for digital computers, especially using autocodes, an for analogue computers, in view of the elaborate setting procedures described in Chapter 2. A good deal of pace is devoted to the study of instability arising from rcuit design. It is a pity that more is not said about fundaental instability arising from the processes used, since there a certain danger of confusion on this subject, of which e authors are evidently aware, but do not discuss. Taken a whole, nevertheless, this is an informative and useful ook.

A. S. Douglas

Electronic engineers' reference book. Edited by L. E. C. Hughes. (London: Heywood and Co. Ltd., 1958.) Pp. 1303. Price 84*s*.

This book, prepared in the style of some well-known chemical reference books, contains 1300 pages of classified information. In the preface the General Editor admits that, for reasons of space, radar, radio and television, telecommunications, wave filters and all service equipment are excluded. Thus, the title of the book could be very misleading for it deals very largely with industrial electronics.

The coverage of the book is wide and varied. It is, however, far from comprehensive and very non-uniform in style and contents. Many items are well discussed, many more might just as well have been left out, and a large number of gaps exist where items which one would certainly expect to find are omitted. Such items as inductance coils, capacitors, the cathode follower, power packs and many such are only mentioned in very restrictive usage. For example, the polystyrene dielectric capacitor is dealt with fully but no other. The design of power packs is omitted. The design of pentode valves receives over 30 pages, but triode and tetrode valves are not considered. Many specific circuits are briefly described but often not in a very useful manner. In spite of the non-uniformity it should be stressed that much useful information is included. The references given are few, and very often are not good ones. The index covers the contents fairly adequately and the format and diagrams are excellent.

M. E. Haine

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Fume cupboard fans. Griffin and George Ltd., Ealing Road, lperton, Wembley, Middlesex. A 4-page illustrated leaflet escribes polythene-coated "Aerofoil" fans which are claimed solve the problem of extracting corrosive fumes without e motor or casing being impaired. The fans are suitable r handling gases at temperatures up to 120° F (49° C).

Flow and pressure measurement and control. George Kent td., Luton, Bedfordshire. Publication 987 describes the ew "Commander" instruments for flow and pressure easurement and control. This range of instruments is tended to cover most industrial applications, and the use f many components common to each form of instrument ermits speedy throughput.

High-vacuum equipment. Consolidated Electrodynamics orporation, Rochester Division, 300 North Sierra Madre illa, Pasadena, California, U.S.A. A general catalogue has ust been issued which describes a wide range of high-vacuum quipment for laboratory and industrial applications.

Alternators. Laurence, Scott and Electromotors Ltd., anfield House, Southampton Street, Strand, London, .C.2. Specification No. 147 deals with a range of alternators esigned to meet the growing need for 400 c/s and other "high" frequency supplies. It is claimed that these machines roduce a good waveform, and a specially low harmonic ontent of the waveform can be insured when required.

Smoke density equipment. Radiovisor Parent Ltd., Stanope Works, High Path, London, S.W.19. A 6-page illusrated folder gives details of smoke density equipment includg smoke time recorders, smoke density indicators, and event ecorders.

Automatic voltage regulators and stabilizers. Claude Lyons Ltd., Stabilizer Division, Valley Works, Ware Road, Hoddesdon, England. A new catalogue (S574) gives details of a wide range of instruments in the a.c. automatic voltage stabilization field. The catalogue contains thirty-nine basic types in six design series.

Electrolytic polisher. Shandon Scientific Co. Ltd., 6 Cromwell Place London, S.W.7. A 6-page brochure describes an electrolytic polisher which can be used for the uniform electro-polishing of metallurgical specimens without the production of flow lines in multiphase alloys.

Autrometer. Philips Electronic Inc., Instruments Division, 750 South Fulton Avenue, Mount Vernon, New York, U.S.A. A new 8-page booklet gives full information on the improved Norelco Autrometer which is an automatic indexing X-ray spectrograph. The text explains the operation of this non-destructive analytical tool and describes how it prints out intensity ratios of 1 to 24 elements in a single sample with elapsed time frequently, it is stated, $\frac{1}{50}$th of that required for chemical analysis.

Length-measuring-machine. Rubert and Co. Ltd., Chapel Street, Stockport Road, Levenshulme, Manchester, 19. An 11-page leaflet gives full details of the Hommel precision length-measuring-machine which is now available in England. These appliances are used for measuring fairly long distances such as those in heavy engineering. The measuring operation is based on a comparison of the length of the sample either with a combination of slip gauges approximately equal to that required or a graduated scale mounted in the bed of the machine—according to the degree of accuracy necessary.

Notes and comments

Symposium on instrumentation and computation in process development and plant design

The Institution of Chemical Engineers, the Society of Instrument Technology and The British Computer Society are to hold a joint symposium on instrumentation and computation in process development. The meeting will be held in the Central Hall, Westminster, London, on the 11, 12 and 13 May, 1959, with subjects and sessions as follows:

- 11 May (morning session): Improving the efficiency of existing processes. (Afternoon session): The design of new processes;
- 12 May (morning session): The application of on-line computers. (Afternoon session): Recent developments in instruments, on-line computers and computers for design;
- 13 May (morning session): (*a*) The use of computer techniques in large and small companies. (*b*) The future (one paper only).

The meeting is being organized under the aegis of The British Conference on Automation and Computation. Any person wishing to present a paper at the symposium should send a summary not later than 1 June, 1958, to The General Secretary, The Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

Electronics exhibition and convention

The thirteenth annual electronics exhibition and convention, organized by the northern division of The Institution of Electronics, will be held during the periods 10–12 July and 14–16 July, 1958, at the Manchester College of Science and Technology. The exhibition will consist of a manufacturers' section and a scientific and industrial research section, including exhibits of interest to all branches of science and industry. The convention will include a series of lectures and film shows on electronic topics. Admission will be free of charge.

Further particulars may be obtained from the Honorary Exhibition Organizer, Mr. W. Birtwistle, 78 Shaw Road, Rochdale, Lancashire.

Pakistan journal of scientific and industrial research

We have received the first issue of a new quarterly periodical entitled *Pakistan journal of scientific and industrial research*, edited by Dr. M. M. Qurashi and published by the Pakistan Council of Scientific and Industrial Research, Karachi. Among the papers included are the following: Radio frequency transmission system of a 30 MEV electron cyclotron; Scattering of high energy electrons by electrons in nuclear emulsion; Proton-proton scattering at medium-high energies; Design and study of audio-amplifier and radio-receiver us
transistors; Design of an improved type of dry cell; Stud
in the properties of heat insulating building materials. Pa
—Cement-rice husk ash mixtures.

The price of the annual volume is Rs. 15, post free, a
single parts Rs. 4, post free. Further details may be obtai
from the publishers.

We wish the latest of the many additions to our c
temporaries all success.

1958 Waverley Gold Medal essay competition

This competition, sponsored by the magazine *Resear*
is designed to draw attention to the problem of commu
cating scientific information to the layman and also
scientists engaged in other fields.

The Waverley Gold Medal and £100 will be awarded
the best essay of about 3000 words based on some rec
scientific research or new development (whether the autho
work or not), giving some indication of the scientific ba
ground, the experimental results and its potential applicat
in industry. The essays will be judged for technical conte
by specialists in that field, for clarity of presentation a
style.

A second prize of £50 will also be awarded and an additio
prize, also of £50, for the best entry from a competitor un
30 years of age on the 31 July, 1958. The competition
only open to persons at present engaged in scientific wo
and the closing date for entries is 31 July, 1958.

Further details may be obtained from the Editor, *Resear*
4–5 Bell Yard, London, W.C.2.

British Journal of Applied Physics

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The Physical Society's Exhibition—London, 1958

By A. J. Philpot, C.B.E., M.A., B.Sc., F.Inst.P.

A general survey is given of the newer developments of instruments and apparatus exhibited.

ie Physical Society's 42nd Exhibition of Scientific Instruents and Apparatus was held in the two halls of the Royal orticultural Society from 24–27 March. The two halls re completely filled by the 133 exhibitors, and the number visitors was greater than at any previous exhibition of the ciety—21,600 persons passing through the turnstiles. evertheless, the exhibition did not appear to be so uncomrtably crowded as it has often been in the recent past, and parently a more even spread of visitors over the hours of ening has been achieved.

The exhibition was opened by the President of the Physical ciety, Prof. N. F. Mott, who stressed the educational lue of the exhibition and congratulated the exhibitors not ly on the quality of the exhibits but also on the research nd development which was of necessity a background to em. He added a salutary word on the wisdom of mainining and, in fact, increasing their research effort.

The holding of the Physical Society's exhibition is most mly and happily married to the production by the Society ch year of a comprehensive *Handbook of Scientific Instruents and Apparatus*.* This publication, whilst acting immeiately as a guide to the exhibition, does provide an annual onspectus of modern scientific instrument development and roduction and, as such, finds its way all over the world. ertainly this article is not intended as a substitute for the erusal of the *Handbook*, for any article adequately describing e exhibition and the exhibits would itself have to be of the ature of a second *Handbook*.

One slight criticism of the exhibition might, perhaps, be oiced at this point. Every regular visitor to this exhibition nows in advance that, during a day's visit, he will not be ble to see all that he would like to see, or all that he feels e should see. There is so much in the exhibits and demonrations of interest to anyone, whatever his particular field, oncerned with the use and possibilities of use of scientific nstruments, that the visitor, however firmly he may resolve steer his viewing into pre-determined channels, finds imself wandering into by-paths of interests with a consequent recking of his tight programme. How essential it is, thereore, that every help should be given to visitors by the exhibiors. Every exhibit is supposed to be novel in principle or incorporate some novel characteristic in design or operaion and a very high proportion of the exhibits does in fact onform to the condition of novelty. It would be extremely elpful if this focal point of interest of an exhibit could be learly set forth on a printed card so that the visitor could mmediately assess his interest in the exhibit. Such a practice ould save the time of the visitors and conserve the patience f the demonstrators. In point of fact the proportion of xhibits so documented is relatively small.

The recent exhibition was of special interest in that it howed that a particular development of instrument design and use has evidently achieved a considerable measure of maturity. It is common knowledge that in connexion with the Physical Society's exhibitions held during the post-war years there have been murmurings, and the writer must confess he has added to their volume, about the appropriateness of the display of metal boxes, apparently hermetically sealed, with their façade of knobs and dials so often incorporating as a centrepiece the viewing end of a cathode-ray tube. Doubt has been expressed as to whether an electronic device was an instrument within the framework of the traditions of the Physical Society. The electronic counting and scaling devices which have been shown more recently, having great variety of purpose but much similarity of appearance, have been the subject of the same doubt. It is most salutary and yet fascinating to find that the "old-fashioned honest instrument" which has been the object of so much nostalgic remembrance during these recent years has now re-emerged inextricably linked with the electronic devices. There was until recent years a grade of junior scientific workers known as "observers"; their main occupation was the taking of readings and recording them. Their records were often passed to others for checking, evaluation, and interpretation. This year's exhibition has made it more clear than any previous one that the function of the observer is becoming obsolescent and that in every part of the field of instrument use his work is being taken over by some form of electronic device. The "black box" takes the readings and records them either transitorily on the cathode-ray tube or permanently on photographic or recording paper.

Such observations may well in the year 1958 seem somewhat trite but, nevertheless, a revolution in the art and methods of experimental observation must be of interest and certainly has significance. Especially is this so when the further change clearly shown in the exhibition is considered. More and more is the work of evaluation and interpretation of the information, supplied by the use of instruments, being achieved by electrical computational methods and this is true even in respect of the use of traditional instruments. Three examples must suffice. Two microscope makers, Cooke, Troughton and Simms Ltd., and Hilger and Watts Ltd. (Fig. 1), showed microscopes with special mechanical stages and "counter" attachments, which indicated by the counters either the number of particles in, or the relative areas of, the constituents of a specimen examined with the microscopes. Dr. E. T. Hall in his discourse on "Some uses of physics in archeology" gave a demonstration of an automatic X-ray fluorescent spectrometer shown by Solartron Electronic Group Ltd., in which the constituents of a specimen emit their own characteristic X-ray beams. The various beams are isolated by crystal diffraction and the relative strengths of the beams are automatically indicated on a scaler device. In the field of surveying instruments the Ministry of Supply showed a prototype recording stereo-comparator used to determine the plane co-ordinates of the same points of detail on two overlapping aerial photographs. The information extracted by the comparator appears in the form of punched cards or tape suitable for use in high-speed computing machines. To one who watched the early efforts of co-ordination of aerial photographs in the First World War this modern instrument with its elimination of human assessment was specially interesting. The past twelve months have witnessed a marked advance in the linking of counters and computers to instruments for the purpose of recording, evaluating and interpreting information supplied by the instruments. We are, in fact, at the end of one era and at the beginning of another as far as experimental practice and procedure is concerned.

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* Copies are obtainable from The Physical Society, 1 Lowther ardens, Prince Consort Road, London, S.W.7. Price 7*s*. 8*d*. ncluding postage and packing.

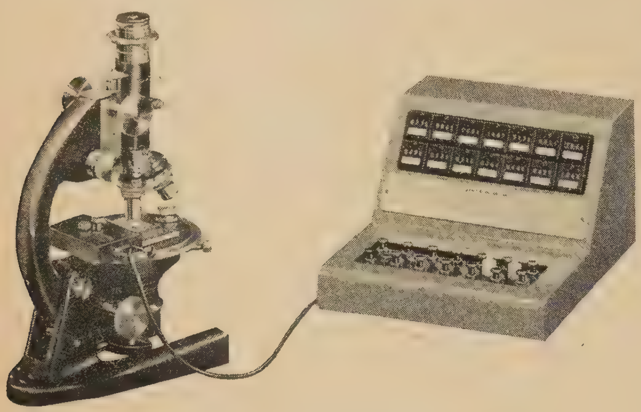

Fig. 1. Automatic point counter for use with microscope

It used to be said that one chemical laboratory was much like any other, and there existed a standard mental picture of this type of laboratory in which there was a general background of reagent bottles. The exhibition this year has provided further evidence of the extent to which physical methods and instruments are being used in the fields of chemical detection and analysis. The use of some physical methods for these purposes is, of course, of long standing. The quantitative assessment of gases in small proportion through changes in heat conductivity has a long history. More recently changes in the absorption of infra-red radiation have been used to the same end. The achievement of chemical analysis through X-ray diffraction and infra-red, visual and ultra-violet spectrography is firmly established both in laboratory and works practice. (These have, however, as already indicated, become much more effective and rapid in action through their linkage with computational devices.) The exhibition showed that this process is still rapidly growing. The use of microscopes with counter attachments and of fluorescent X-ray diffraction with a scaler unit for purposes of chemical analysis has already been mentioned. The development of the flame photometer as an instrument for the measurement of quantities of elements present in minute proportions still continues in a lively manner. The National Research Development Corporation exhibited an ultra-micro flame spectrophotometer which, it was claimed, is capable of determining micromicrogramme amounts of strong light emitting elements; thus it will detect as little as 3×10^{-13} g of sodium. The Atomic Energy Research Establishment, Harwell, has developed a special flame photometer attachment for the Uvispek monochromator to meet its own particular needs, the whole being suitable for direct reading, integration, or internal standard methods of flame photometry with automatic background correction. Unicam Instruments Ltd. displayed a flame photometer with monochromator and electronic equipment (Fig. 2) wh gives a direct reading of emission line intensity, and Bald Instrument Co. Ltd. exhibited a flame photometer speci designed for the quick and accurate determination of calc in blood sera.

The Divisions of Bio-chemistry and Engineering of Medical Research Council gave two demonstrations of n methods of measurement of gas concentrations. A de for the detection of low concentrations of organic vapo makes use of the fact that ionizing radiations produce in rare gases relatively large concentrations of metastable at which, on collision with organic vapour molecules, prod ions. In this device the presence of organic vapour is in cated by an increase in the ionization current and sensiti achieved by this method is such that concentrations vapour as low as one part in 10^{10} can be detected. Pneumoconiosis Research Unit of the Medical Resea Council demonstrated a device by which nitrogen can be c tinuously analysed in the presence of other respiratory gas The gases are drawn at a constant rate into a discharge tu and variations in the intensity of the light emitted by tube furnish a measure of nitrogen concentration.

In addition to the instances given above of the exten uses of physical principles in chemical analysis further p gress has been made in the development of continuous a automatic methods of carrying out chemical analytical p cesses of the orthodox type. Baird and Tatlock (Lond Ltd. have extended their range of "Analmatic" instrume and demonstrated an analyser for grouped individ samples. The combination shown is in use for the chemi assay of 400 daily samples of penicillin at the Glaxo Labo tories. Electronic Instruments Ltd. showed a titroma analyser, developed in conjunction with Imperial Chemic Industries Ltd. which automatically carries out the analy of chemical products during the course of manufacture. regular intervals a measured quantity of the product is draw off and titrated and the results of the titrations are shown a continuous recorder chart. We have remarked that this the end of an era in respect of the practice of experiment

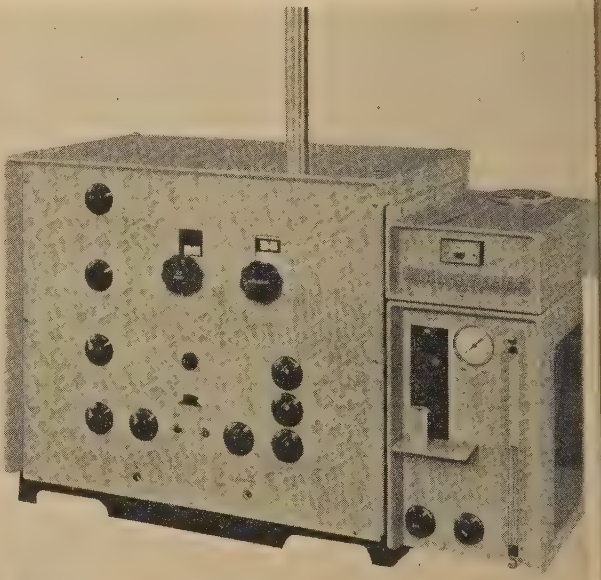

Fig. 2. Flame photometer with monochromator and electronic equipment

ysics. The remark would appear to be equally applicable the practice of chemical analysis.

The large measure of scientific control which now exists the manufacturing industries has meant that in many works oratories the number of daily weighings required to be ade with any one balance is fantastically high. It is not sur- sing, therefore, that during the last decade balance-makers ve largely concentrated in their designs on speed of weigh- g, with no loss of precision, and on achieving the greatest ssible economy in the movement and use of weights. It is ident from the balances shown this year that the one-pan lance is much in favour for rapid and routine weighing and w models of this type were shown by three firms, L. Oertling d., Stanton Instruments Ltd., and J. W. Towers and Co. d. The balance of to-day is much more rapid in action, ich more robust, and much less dependent on the manipu- ive skill of the user than was its predecessor of a generation o. Nevertheless the basic working principles of balance sign remain much the same and, possibly, of all instruments e balance has been least affected by the existing ubiquitous e of amplification by electronics. For research purposes her principles of balance design are introduced from time time and this year two research exhibits included less rmal methods of indicating beam displacements. In the scription of the recording balance for use in thermo- avimetry demonstrated by the Chemical Inspectorate of the inistry of Supply it is recorded that "the off-balance of the am is detected by a linear variable differential transformer" d the description of a "self-recording magnetic balance" monstrated by the University of Durham, King's College, ewcastle upon Tyne, says, "the movement of the beam is easured by a photocell, the amplified output from which is ed to provide a controlling force . . . reducing deflexion arly to zero."

Some three years ago the British Scientific Instrument esearch Association published a monograph on flexure evices in instruments. The Association has evidently been ating out of its own cupboard" since it provided a demon- ration of a one-pan balance in which knife-edges were placed by flexure pivots.

A prototype quartz-fibre micro-balance was shown by L. Oertling Ltd. (Fig. 3). This instrument, designed to weigh with an accuracy of $0 \cdot 1\ \mu g$ for loads up to $0 \cdot 5$ g, had an extremely serviceable appearance.

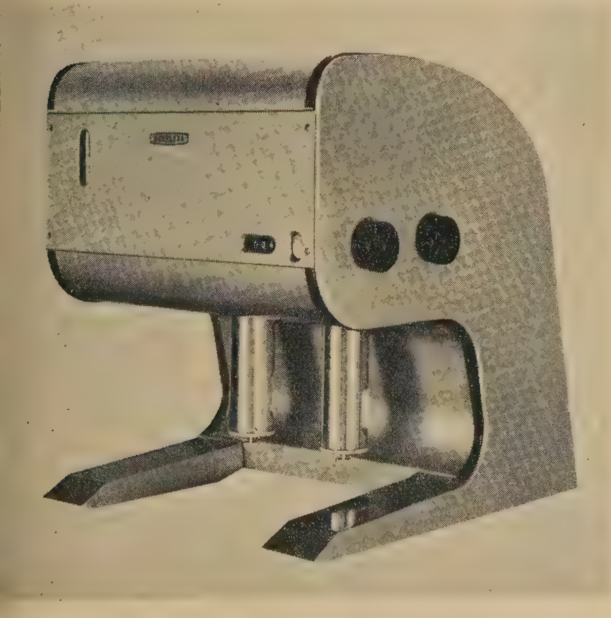

Fig. 3. Quartz fibre ultra micro-balance

Two very interesting exhibits were the high resolution magnetic resonance spectrometers shown by Mullard Ltd. and by Metropolitan-Vickers Electrical Co. Ltd. These instruments certainly provide an example of a very speedy incorporation of current scientific knowledge into the design of a new type of instrument. Although at the moment the nuclear magnetic spectrometer is primarily a research tool mainly used to obtain information about atomic structure, the instrument has evident possibilities in the field of process control, and it will be interesting to note how speedily further developments of applied use take place. The President of the Society in opening the exhibition made special reference to the possibilities of development of this instrument.

The emergence of new optical material is always a matter of interest, and the synthetic fused silica shown by the Thermal Syndicate Ltd. appears to be so superior in its optical properties to the fused quartz of optical quality as almost to be considered a new optical material. The degree of purity achieved is such that no coloration occurs in the material as a result of exposure to gamma-rays and other destructive radiations and the material transmits ultra-violet light freely, well below the old limit of 2000 Å.

Chance-Pilkington Optical Works, Pilkington Bros. Ltd. displayed specimens of optical glasses manufactured by the new continuous-tank method. The increased "whiteness" and the absence of "bubble" in glasses so made are very striking.

A new workshop process frequently leads to changes in instrument design. The development of the argon arc process has opened up possibilities of design in various directions, and Kelvin and Hughes Ltd. showed pressure capsules in Ni-Span "C," Austenitic stainless steel, Monel and Inconel, the production of which has been made possible by the use of the argon arc technique. Pressure capsules have performed many useful purposes over many years but have had associated with them certain obdurate tendencies to variability. Any new type of capsule is therefore to be welcomed.

The research laboratory of British Thomson-Houston Co. Ltd. showed an interesting device for converting an infra-red picture into a visual one. The device consists essentially of large area photoconducting and electroluminescent layers sandwiched in series between two transparent conducting electrodes. An alternating voltage is applied between the electrodes and the intensity of incident radiation upon any particular discrete area of the photoconducting layers controls the electric field through the device and hence the brightness of the corresponding electroluminescent area. A demonstration was given of the conversion of a picture of low definition.

As was to be expected there was a most impressive and, in many respects, fascinating display of counting, scaling and digitizing apparatus by many firms well known for their interest in these fields as well as by some newcomers. The rapidly expanding use of these devices in so many fields must mean that, for some time, continuous development will take place, directed towards increasing the adaptability of the various types of computers to meet the conditions of particular and peculiar uses; and, in consequence, new special-purpose scalers and counters will appear in the exhibition from year to year. This brings one to remark that there is a secondary function of the exhibition which should have very great value. The primary function of the exhibition is, of course, to provide a shop window (not a shop!) in which all interested in instruments and their use may see all that is latest and novel in instrument design and operation and the attendance at the exhibition shows that this function is carried out in large measure. But the exhibition can render great service to the exhibitors themselves quite apart from the publicity given to their exhibits. Any lively-minded and forward-looking instrument-maker must surely find it exhilarating to have close at hand research exhibits which so often contain the embryonic ideas which will most surely develop in time into new instrumental devices, and to have displayed around him the auxiliary devices the use of which may keep his instruments abreast of the times. Also the instrument maker must ask himself why a research institution has gone to great lengths to produce an instrument of a type which he himself manufactures as, indeed, conversely the research exhibitor must sometimes ask himself why he made this effort when so many instruments are to be seen having the same or very similar functions. The exhibition should be a source of great inspiration to the exhibitors, makers and users alike, and it is to be fervently hoped that the scientific and technological personnel who man the stands and, be it said, gave of their best during the exhibition, find the opportunity themselves of gaining the maximum benefit from seeing all that is happening outside their own specialist and immediate interests.

The traditional discourses were given on each of the three evenings of the exhibition and the lecture hall was crowded on each occasion. The lecturers were Mr. M. H. Wilson on "Goethe's colour experiments," Dr. E. T. Hall on "Some uses of physics in archeology," and Mr. R. J. Murgatroyd on "Some recent investigations with aircraft on the physics of clouds and rain."

CRAFTSMANSHIP AND DRAUGHTSMANSHIP COMPETITION

Those in charge of this annual competition held in conjunction with the exhibition, have felt for some time that it was being overweighted by entries in the gauge and tool and draughtsmanship classes. In consequence it was felt that main purpose of the competition, namely to encourage yo instrument makers, was being somewhat obscured. As experiment, therefore, these two classes were omitted from year's competition although they may well be partially introduced next year. As is customary the prize-winn entries in the competition were displayed in the entrance of the exhibition and were the object of continuous interested inspection. A copy of the judges' report and list of prize-winners is given below.

Judges' Report

In the classes for "scientific instruments and componen and for "sections of instruments, functional scale models scientific interest and patterns" the entries were reasona well up to standard. The prize-winning entries were of extremely high standard. Quite a number of exhibits microweight components did not reflect the high standar craftsmanship of the older type of instrument work. It w appear that there is room for considerable improvemen this direction. The Craftsmanship entries although few number were in general of excellent workmanship.

All five entries in the class for "optical components systems" were excellent examples of accurate glass work and each of the competitors should be complimented on achievement. All surfaces, angles and definition tests h been stringently applied.

This year the entries in the "blown glass and silica wa class were a little above normal standard previously sh in this competition. Regarding the silica exhibits, the jud considered that they were of a rather simple standard. to be hoped that in the following year a little more complica pieces of apparatus can be shown.

For the Silvanus P. Thomson prize (in which competit are required to submit a piece of craftsmanship as well their own working drawings of it) the number of entries disappointing and it is to be hoped that something can done to encourage entries for this section of the competiti

Craftsmanship and Draughtsmanship Competition

PRIZE LIST

Scientific instruments and components (Junior grade)

First prize: E. W. STEARN (Cambridge Instrument Co. Ltd.). Special small type cathetometer.

Second prize: J. GRAYSTON (Marconi's Wireless Telegraph Co. Ltd.). 250–500 Mc/s frequency meter.

Third prize: B. J. CASSERLEY (The National Institute for Research in Dairying). Water-jacketed cell holder and carrier for Beckmann photometer.

Honourable mention: E. C. COOPER (Hilger and Watts Ltd., London). Micrometer cell reading 0·01 mm (for use with Spekker ultra-violet and Nutting photometers).

Scientific instruments and components (Senior grade)

First prize: D. N. BISHOP (Marconi's Wireless Telegraph Co. Ltd.). Mechanical resolver block (part of Doppler air navigational aid).

Second prize: J. R. HILL (George Kent Ltd.). Integrator mechanism for potentiometric indicating and recording instrument.

Third prize: M. MERRICK (Marconi's Wireless and Telegraph Co. Ltd.). Magnetic clutch (less windings and modified for manual operation).

I. M. MARRABLE (Hilger and Watts Ltd., Loughton). The up-and-down optical plummet.

Optical components and systems

First prize: F. C. TURVELL (Hilger and Watts Ltd., London). Quartz Cornu prism.

Second prize: D. BINGHAM (Hilger and Watts Ltd., Loughton). 60° master prism.

Blown-glass and silica-ware (Blown-glass)

First prize: A. MOORE (Research Laboratory, Mullard Ltd., Redhill). Ball condenser.

Second prize: H. PATTISON (Research Laboratory, British Thoms Houston Co., Ltd., Rugby). Stage glass mercury diffusion pu

Third prize: S. TILFORD (Research Laboratory, Mullard L Redhill). Annular double surface condenser.

Honourable mention: D. W. LANMAN (Research Laborat British Thomson-Houston Co. Ltd., Rugby). Double surf reflux condenser. J. A. JONES (Research Laboratories, Gene Electric Co. Ltd.). Low resistance liquid-air trap.

Blown-glass and silica-ware (Silica-ware)

First prize: H. PATTISON (Research Laboratory, British Thoms Houston Co., Ltd., Rugby). Single-stage silica mercury diffus pump.

Second prize: G. GOURLAY (The Thermal Syndicate Ltd.). Clai flask in transparent silica.

Honourable mention: K. ROBSON (The Thermal Syndicate Lt 25 ml. specific gravity bottle in transparent silica. D. LANMAN (Research Laboratory, British Thomson-Houston C Ltd., Rugby). Silica condenser.

Sections of instruments, functional scale models of scientific inte and patterns

First prize: J. R. CATTON (Standard Telephones and Cables L N. Woolwich). Toll line stranding machine, excluding ca take up assembly and motive power.

Second prize: A. D. WARREN, (Standard Telephones and Cab Ltd., N. Woolwich). Speedax band saw less motive power.

Third prize: D. PARRIS (Elliott Brothers (London) Ltd. Oldh coupling.

Silvanus P. Thompson prize

D. J. STEVEN (E.M.I. Electronics Ltd., Feltham). Power saw.

Honourable mention: J. A. N. SPEAR (Ministry of Supply, A.I Laboratories, Harefield). $\frac{1}{2}$ in. extensometer (Lamb type).

A cathode-ray tube analogue-to-serial digital converter

By J. Willis, B.Sc., A.M.I.E.E., and M. G. Hartley, M.Sc., Faculty of Technology, University of Manchester

[*Paper first received* 31 *July*, 1957, *and in final form* 10 *February*, 1958]

Small fluctuations of the screen equilibrium potential of a cathode-ray tube cause proportionate small fluctuations in the steady secondary emission current arriving at a collector anode. The application of this fluctuation of secondary emission to an analogue-to-serial digital converter is discussed. An investigation of the parameters affecting changes of secondary emission using an electrode on the face of the tube, maintained at an alternating potential, to vary the screen potential is described. The secondary emission is observed as a signal, developed across a resistor between collector and earth, at screen electrode supply frequency, amplitude-modulated by the changes in secondary emission which occur when the screen is scanned by an electron beam.

The effects of electrode potential, electrode width, steady state collected current, beam focus, bias applied to the collector and accelerating voltage are examined. The results are compared with those predicted from electrolytic tank studies. The variation of output over the screen surface under different operating conditions is discussed. Experiments to determine minimum electrode width and spacing, consistent with the production of a discrete pulse output from each electrode of a pattern, are described.

vo suggestions have been made for the use of a cathode-ray e in an analogue-to-serial digital converter (Fig. 1). In the st(1) a mask is placed between the screen of the tube and photoelectric cell. The analogue potential positions the ight at which the beam sweeps the screen, and pulses of ht fall on the photoelectric cell as the spot crosses the slits the mask. The output is the number of digits correspond- g to the analogue input voltage. The alternative sug- stion(2) is to place the mask inside the tube so that it tercepts the electron beam as it sweeps across the tube, cept at the slits where it causes pulses of current in the llector electrode situated behind the mask.

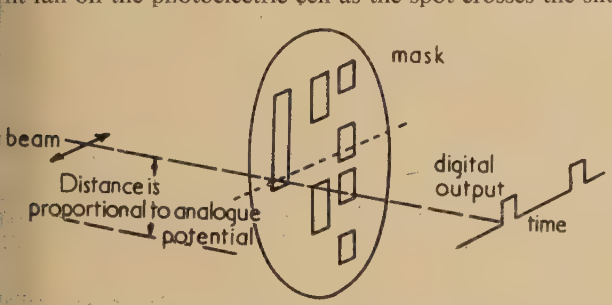

Fig. 1. General principle of analogue-to-digital conversion using mask

Burtt and Willis(3) have shown that when potentials are plied to electrodes attached to the outside of a cathode-ray tube screen, appreciable variation occurs in the secondary emission from the screen as the beam sweeps across the area in the region of the electrodes. This effect can be used to obviate the need for a special tube with built-in mask, or the photoelectric cell and lens system with the external mask. Electrodes are attached to the screen of a normal cathode-ray tube, the electrodes being arranged in a similar pattern to the masks in the original systems. A voltage is developed by the secondary emission current in flowing through a resistor in series with the collector electrode (one of the tube anodes). As the beam sweeps across the screen the variations in secondary emission produce the output pulses in the resistor. The arrangement is shown schematically in Fig. 2.

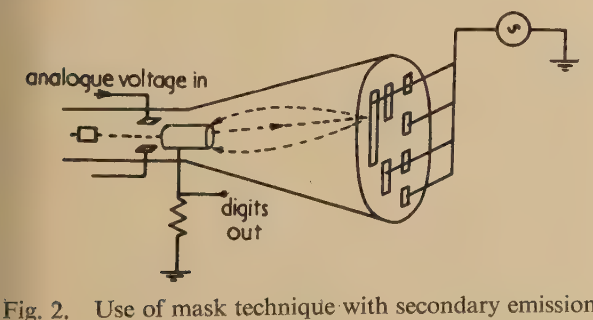

Fig. 2. Use of mask technique with secondary emission from screen

In the following sections the shape of the pulse, and its dependence on the various tube parameters, is described.

ELECTROLYTIC TANK STUDIES

Owing to the fringing of the electric field, the potential distribution on the inner surface of the glass screen will differ from that at the electrode. This will affect the shape of the pulse produced when the spot sweeps across the screen. The width of the pulse will be greater than the width of the electrode, and the sides will have a considerable slope. In addition, the amplitude of the pulse will decrease for small electrode widths.

In order to assess these effects some experiments were carried out in an electrolytic tank with a model of the electrode arrangement. Since there is symmetry in the potential distribution on either side of an electrode, a model of only one-half was constructed. The model is shown schematically in Fig. 3. This corresponds to a strip electrode surrounded by an earthed electrode. This had been found necessary during the experimental work to obtain a sharply defined output pulse. Experiments were performed for various values of α, where α is given by

$$\alpha = \frac{a}{b} = \frac{\text{width of electrode}}{\text{thickness of the glass of the tube screen}}$$

The curves of Fig. 4 show the potential at the inner surface of the screen as a percentage of the potential applied to the electrode, plotted against distance from the centre line of the electrode strip. Curves for various values of α are given.

The amplitude of the potential directly behind the centre line of the electrode increases with α up to a value of $\alpha = 6$ approximately. The potential on the inside of the screen in the actual equipment will be modified by the secondary emission process. Whilst it is not to be expected that the curves will agree accurately with the pulse shapes obtained experimentally, it will be seen later that they do indicate the general trend.

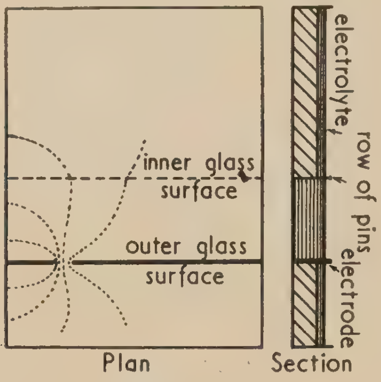

Fig. 3. Electrolytic tank

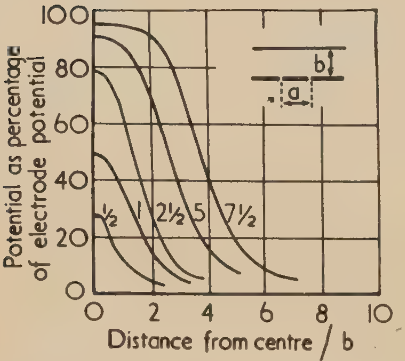

Fig. 4. Potential along inner surface of screen for various values of $\alpha = a/b$ as determined from electrolytic tank measurements

For a particular tube having a fixed screen thickness b, the results from the electrolytic tank experiments indicate that the maximum pulse amplitude should be attained when the electrode width is about six times the screen thickness.

EXPERIMENTAL TECHNIQUE EMPLOYED

The Cossor tube type 09, which has, in addition to the conventional three anode "electron gun," a cylindrical anode A_4 at the neck of the tube, proved very suitable for the experimental work, anode A_4 being used as a collector for secondary electrons. The electrodes consisted of strips of metallic foil gummed to the face of the tube. On the application of an alternating potential to the strips, the screen material in the region of the spot fluctuates about its mean potential. The resulting small alternating component superimposed on the steady secondary emission current collected at A_4 develops an alternating voltage output across a resistor connected between A_4 and earth. This occurs each time the electron beam passes an electrode strip. A simplified bl diagram of the equipment is given in Fig. 5.

A frequency of the order of 1 Mc/s was used for the scr electrode potential, so that several excursions from equilibrium condition occurred while the beam was travers an electrode. An output was observed, even when the be was not opposite an electrode, owing to the capacita between the strips and A_4.

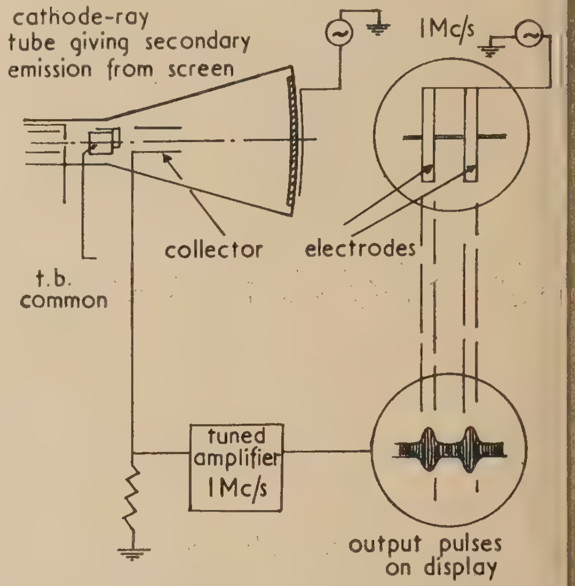

Fig. 5. Block diagram of equipment showing outpu resulting from beam scanning two electrodes

In order to facilitate measurement, the modulated outp waveform was amplified, demodulated and further amplifi The resulting pulse output was displayed on a cathode- tube. Since the gain of the amplifier was known, it w possible to determine the magnitude of the initial outp waveform developed across the resistor.

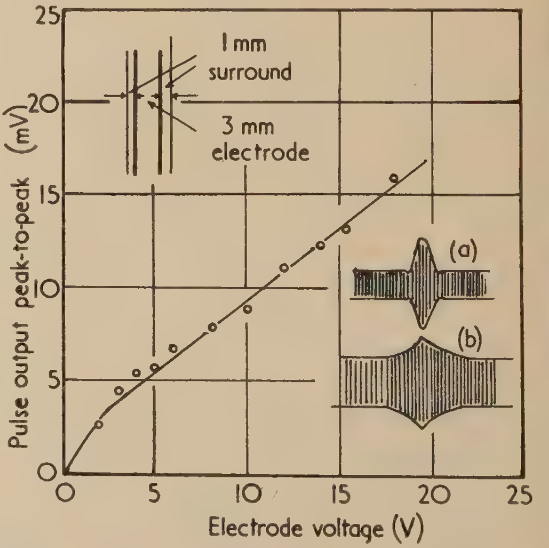

Fig. 6. Pulse amplitude *versus* electrode voltage

(*a*) Typical display with surround earthed.
(*b*) Typical display with surround no longer tied to earth potential.

EFFECT OF ELECTRODE POTENTIAL AND ELECTRODE DIMENSIONS

a) *Effect of electrode potential.* The relationship between voltage applied to the electrode on the front of the tube, d the magnitude of the output pulse is given in Fig. 6. cept for small electrode voltages the relation between the ctrode potential and the pulse output is substantially linear. r an electrode voltage of 20 V the output pulse has peak-to-ak amplitude of the order of 16 mV.

b) *Effect of electrode width.* As shown in Fig. 7, for ctrode widths greater than about 6 mm the pulse output ndependent of the electrode width. Owing to the fringing the electric field, the pulse width is greater than the strip dth in all cases, while for electrodes less than 7 mm, the ld for a given electrode potential is reduced on the inside the screen. This reduction in field causes a decrease in lse amplitude. The pulse amplitude is proportional to ip width for strips less than 6 mm wide.

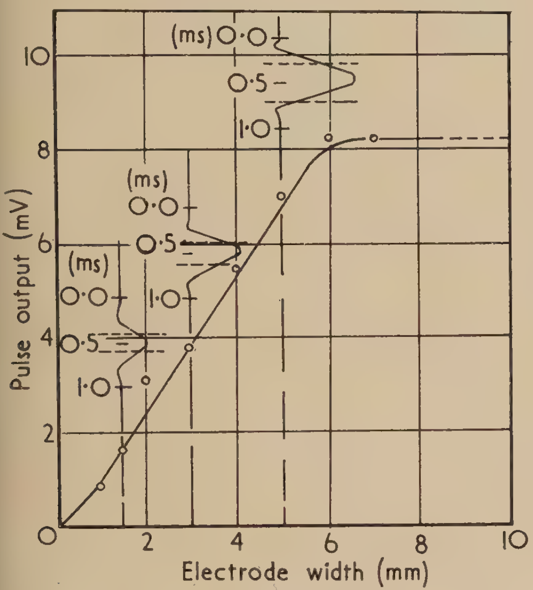

Fig. 7. Pulse output *versus* electrode width. Electrode potential 20 V

Since the glass of the tube screen is approximately 1½ mm ick in the case of the type 09 tube, this experimental result in accord with the result obtained from the experiments ing the electrolytic tank.

FACTORS AFFECTING OUTPUT FROM THE CENTRE OF THE SCREEN

A single electrode placed at the centre of the screen was nployed to study the variation of the secondary emission lse output from the centre of the screen with changes in e operating conditions. To obtain a better-defined pulse ape, the electrode was surrounded by an earthed strip hich improved the shape of the pulse.

(*a*) *Effect of beam width.* Previous tests were carried out th the beam in the focused condition and the line width its minimum value. A check on the variation of pulse tput with changes in the beam width was made. The sults are shown in Fig. 8. The beam width was varied by ljustment of the voltage applied to the focusing anode A_2, travelling microscope being used to measure the line width.

As the collected current increases through the focused condition, the pulse amplitude also increases at the same rate up to a value of I_{A4} of about 12 μA. After this value, at a line width of about 4 mm, the pulse amplitude begins to fall off. In the type 09 tube, anode A_4 takes the form of a cylinder. As the beam becomes increasingly diffuse, the proportion of the collected current consisting of primary electrons impinging directly on to the surface of the cylindrical anode A_4 increases. Hence the effective beam current impinging directly on the screen is reduced, resulting in the diminished pulse output.

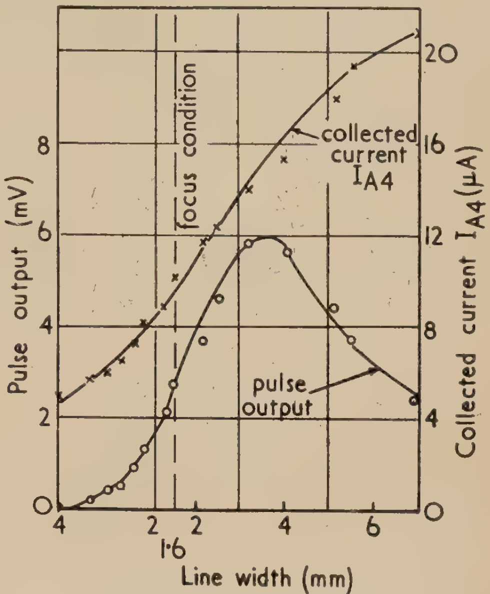

Fig. 8. Line width *versus* pulse output and collected current I_{A4} 4 mm electrode at 30 V

(*b*) *Effect of collector-electrode potential.* Fig. 9 indicates that although the collector current I_{A4} continues to increase as the collector electrode is made progressively positive, the pulse amplitude reaches a maximum for a positive bias of about 50 V. Above this value an increasing proportion of the collected current consists of primary electrons attracted to the positive collector in preference to the screen. The reduction in the number of electrons impinging on the screen

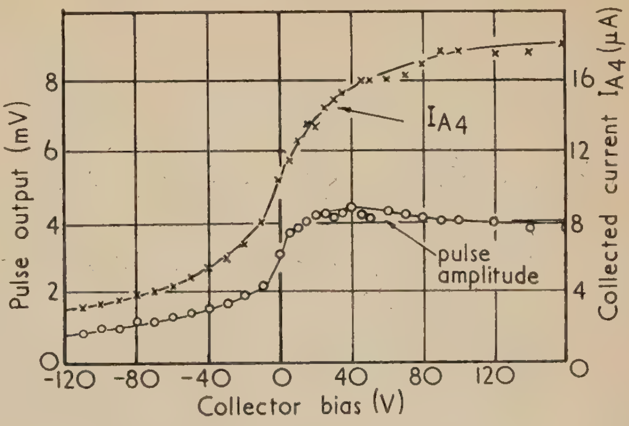

Fig. 9. Pulse output and collected current *versus* bias voltage. 4 mm electrode at 20 V

results in a smaller secondary emission current, and hence a smaller pulse amplitude. When negative bias is applied the electron flow is reduced, and the collected current and the pulse amplitude both diminish.

(*c*) *Effect of steady accelerating voltage.* The effect of variation of the accelerating voltage from the normal value of 1200 V was considered. Since the focus of the beam had a considerable effect on the collected current and pulse output, the spot was focused before each reading. Fig. 10 shows the results. As expected the pulse amplitude is proportional to accelerating voltage. The scatter of the points about the curve is due to the resetting of the focus control at each value of accelerating voltage.

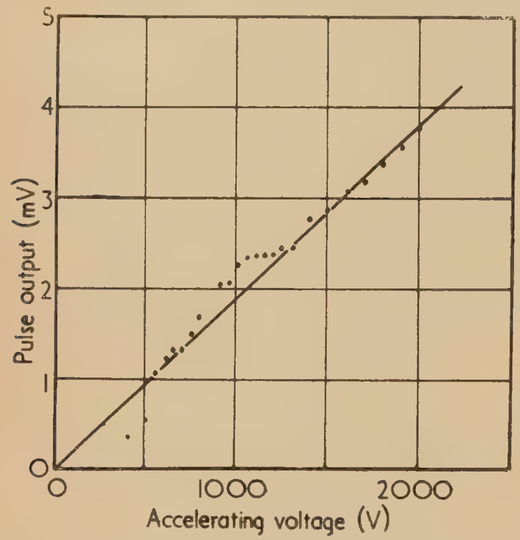

Fig. 10. Pulse output *versus* accelerating voltage

(*d*) *Effect of sweep speed.* The sweep speed of the electron beam was maintained constant at 12 mm/ms during the experimental work. However, the effect of variation of sweep speed over a wide range was considered. The pulse output proved to be substantially constant over the sweep speed range 3 to 3000 mm/ms.

VARIATION OF OUTPUT OVER THE SCREEN SURFACE

With electrostatic deflexion of the beam the response differs at various parts of the screen. This variation of pulse output over the screen surface when different methods were used to deflect the electron beam was measured over the central 6 cm square area. The output was obtained by the use of a 4 mm strip electrode, maintained at 20 V, which was moved to various positions over the screen surface.

Fig. 11 shows the secondary emission output, measured in millivolts, for the Y_1 beam when the normal sawtooth time-base, scanning the screen from left to right, is applied, and electrostatic deflexion is used in the Y-direction. The type 09 tube is a double-beam tube with a "splitter" plate between the Y plates to produce the two beams. For positions of the Y_1 beam below the horizontal axis of the tube, the splitter plate collects directly an increasingly greater proportion of the primary beam current, thus reducing the beam current incident at the screen. The secondary emission current is reduced in the same proportion. The pulse amplitude is directly proportional to the steady collected secondary emission current I_{A4}. Hence the pulse amplitude for the beam falls off at the bottom of the screen.

The time-base is normally applied to the X_1 plate. Wh the X_1 plate is positive, part of the primary beam curren diverted to the deflector plate. This results in diminish secondary emission output. Owing to these effects maximum output occurs in the first quadrant of the scree as shown in Fig. 11. The effect of using the Y_2 beam, a of reversing the time-base, is to cause the maximum outp to occur in the other quadrants.

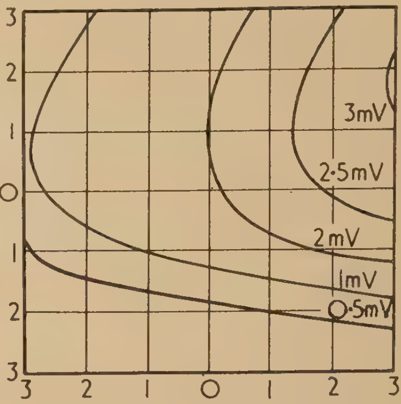

Fig. 11. Variation of output over the screen surface Normal operation of electrostatic time base. Y_1 bea

(Co-ordinates show distances from the centre of the screen i centimetres)

When a magnetic time-base is used to replace the electr static-horizontal deflexion, the assymmetry is limited to th due to the use of the Y_1 and Y_2 plates. The trend is sho in Fig. 12. When magnetic deflexion is employed on bo axes, both beams are coincident owing to the absence of t usual shift controls. Under these conditions the output ov the central part of the screen is substantially constant.

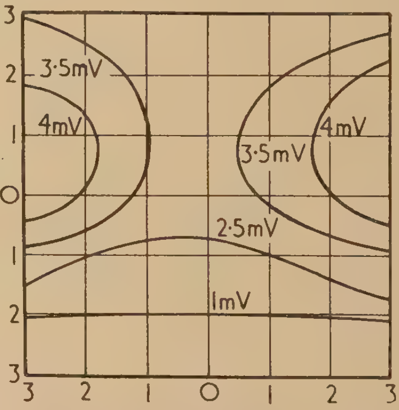

Fig. 12. Variation of output over the screen. Magnetic time base, electrostatic deflexion on Y axis

(Co-ordinates show distances from the centre of the screen ir centimetres.)

PERFORMANCE OF VARIOUS TUBES

In order to assess the variation of the secondary emissi effect from one tube to the next, the performance of fi type 09 tubes was compared by measurement of the outp tained from the centre of their screen material under the me conditions.

The table gives the pulse output obtained from the centre the screen for both the Y_1 and the Y_2 beams. Although e amplitudes obtained are of the same order of magnitude, ere are considerable differences between the various tubes. is is to be expected since the pulse amplitude is a function a number of variables. The important parameters include:

- (i) slight variations in the composition and thickness of the deposition of the screen material from tube to tube. These are inherent in the tube itself and cannot be modified;
- (ii) variation in cathode emission current $I_{cathode}$. This is dependent on the cathode heater voltage, and also on the particular tube and its age;
- (iii) variation of the collected current I_{A4}, which is a function of the cathode current and, under certain conditions, of the focus of the beam;
- (iv) sharpness of focus of the electron beam. The minimum possible beam width varies from tube to tube;
- (v) accelerating voltage applied to the tube. This parameter and those which follow are dependent on the experimental conditions;
- (vi) amplifier gain. For this to be constant the h.t. and heater supplies to the amplifier must be stabilized;
- (vii) supply voltage to the electrodes, which must be kept constant;
- (viii) accurate positioning of the electrode on the vertical diameter of tube, and the electron beam on the horizontal diameter.

ulse output from the centre of the screen for five type 09 *tubes*

(4 mm electrode. Electrode potential 20 V at 1 Mc/s.)

Tube	1	2	3	4	5
utput for Y_1 *beam* (mV)	3·4	1·8	1·9	3·1	2·8
utput for Y_2 *beam* (mV)	2·6	1·6	1·1	3·7	1·9
ollected current Y_1 *beam* (μA)	11·0	6·3	8·7	10·5	9·0
ollected current Y_2 *beam* (μA)	9·6	6·0	6·7	10·2	9·0
$_{cathode}$ *for* Y_1 *beam* (μA)	363	324	340	382	455
$_{cathode}$ *for* Y_2 *beam* (μA)	375	324	355	370	430

EXPERIMENTS ON MULTI-ELECTRODE SYSTEMS

(*a*) *Minimum electrode width and spacing.* In general a number of electrodes are required. The minimum electrode width, and the minimum spacing of electrodes consistent with the production of a discrete pulse as the electron beam sweeps past each electrode of a set, were experimentally determined. Owing to the fringing of the field at the edges of the electrodes, individual pulses were difficult to distinguish.

To improve the pulse shape a strip of foil of the order of 1 mm wide was placed between each of the electrodes. This was supplied at the same frequency as the electrodes with a potential of the same order of magnitude as the electrode potential, but in antiphase. These strips had the effect of confining the charged regions of the screen to the areas directly beneath the electrodes, and their use resulted in a considerable improvement in the shape of the pulse output.

The series of experiments resulted in the following general conclusions:

- (i) for the type 09 tube, good resolution is obtained with electrodes as narrow as 2 mm wide with 1 mm spacing strips in antiphase;
- (ii) best results are obtained when the antiphase voltage is approximately equal and opposite to that applied to the electrodes. The exact value depends on the relative widths of the electrodes and antiphase strips, and their relative distances from the face of the tube.

(*b*) *Systems of "stepped" electrodes.* In an analogue-to-digital converter a system of electrodes of various lengths, arranged in a particular "stepped" pattern, is used to obtain output pulses representing the digital equivalent, or the binary equivalent of an input analogue voltage applied to the Y deflector plate. Fig. 13 illustrates typical electrode systems for both digital and binary systems. For simplicity the antiphase spacing strips are omitted. Experiments were performed using digital output systems to determine the minimum possible value of step height for the type 09 tube. With 2 mm electrodes these experiments show that satisfactory results are obtained for step heights as small as 2 mm.

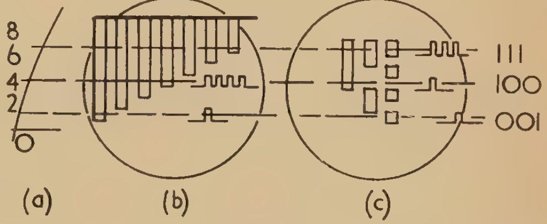

Fig. 13. Electrode systems for both digital and binary systems

(*a*) Analogue quantity.
(*b*) Electrodes for corresponding digit output.
(*c*) Electrodes for binary output.

CONCLUSIONS

Existing cathode-ray tube converters require special tubes with internal masks, or use an external mask with a lens system and a photocell.

The series of experiments described indicates that the secondary emission from the screen of a cathode-ray tube could be utilized in an analogue-to-digital converter.

Provided that the rate at which the beam sweeps the electrode system is much more rapid than the rate at which the analogue voltage is varying, the number of output pulses per sweep represents the digital equivalent of the analogue voltage at the instant of sweep. Since it has been observed that the pulse output is substantially constant over a wide range of sweep speed, a considerable variation in the sampling rate of the analogue quantity can be achieved. It will be seen from the results obtained that digit rates of the order of 1 Mc/s can easily be achieved using conventional power supplies and scanning techniques.

It has been seen that the use of antiphase spacing strips increases both the magnitude and the resolution of the pulse output, and permits of narrow electrode widths and small step heights. This is important since, for the highest accuracy in conversion, the maximum number of electrodes must be used. Ambiguities which result from the beam scanning the edges of two or more electrodes can be dealt with by the use of electrodes arranged in a cyclic code. This would confine ambiguities to the least significant binary digit.

Although the pulse output varies from one tube to the next, the results are sufficiently consistent for any tube of a particular type to be used.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. E. N. Pickering, of the College of Science and Technology, Manchester, for the field plots which enabled the curves of Fig. 4 to drawn.

REFERENCES

(1) Lippel, B. *A High-Precision Analog-to-Digital Conver* Vol. 7. Proc. National Electronics Confere (Chicago: Proceedings of National Electronics C ference, 1952).

(2) Sears, R. W. *Bell Lab. Record*, **26** (10), p. 411 (1948

(3) Burtt, R. B., and Willis, J. *J. Sci. Instrum.*, **34**, pp. 1 182 (1957).

An ultra-micro flame spectrophotometer*

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[*Paper first received* 7 *August, and in final form* 19 *December*, 1957]

A description is given of a modified Beckman DU flame spectrophotometer fitted with an integrating circuit. An electronic switching arrangement is incorporated which enables accurate integration from small volumes of liquid. It is 1000 times more sensitive than the original Beckman instrument. Burning the samples dissolved in acetone increases the sensitivity to 60 000 times, when 3×10^{-13} g of sodium and 10^{-10} g of magnesium can be detected; 1–10 μmg amounts of the latter element in biological fluids have been estimated. The instrument can be used as a direct-recording device without integration. Switching arrangements enable it to be used as the original Beckman DU spectrophotometer both for absorptiometry and flame photometry.

The construction of the instrument described in this paper arose from the need to determine 1–50 μmg magnesium in biological fluids. Existing colorimetric methods are relatively unspecific and not sufficiently sensitive. The flame photometers of Barnes, Richardson, Berry and Hood,(1) Belke and Dierkesmann(2) and Domingo and Kylne(3) are also not sufficiently sensitive, whilst the ultra-micro flame photometric apparatus of Ramsay and Brown(4) and its modification by Bott(5) is only suitable for the determination of sodium and potassium. The most sensitive instrument yet available is the Beckman(6) DU flame spectrophotometer with a photomultiplier attachment, which can detect 1 μg magnesium and determine quantitatively amounts from 10 μg upwards. The Beckman instrument uses an integral burner atomizer, together with an oxy-hydrogen or oxy-acetylene flame to excite the spectrum. For ultra-micro work it suffers from the disadvantage that it takes about thirty seconds to obtain a steady reading, and during this time 1 ml. of solution is atomized. The present instrument has been designed by modifying the existing electrical circuits of the Beckman DU spectrophotometer, and by the addition of a circuit which integrates the total signal from 100 μl. of material fed into the flame. The instrument is 1000 times more sensitive than the original Beckman flame spectrophotometer, and if acetone is added to the sample this sensitivity is increased to 60 000 times. (Acetone has the advantage that it enhances the signal of most of the 45 elements detectable.) With the modified instrument 3×10^{-13} g sodium and 10^{-10} g magnesium can be detected, and amounts of magnesium from 1×10^{-9} g upwards can be quantitatively determined. Switching arrangements are incorporated, so that instrument can still be used as a normal spectrophotome both for absorptiometry and flame photometry, and it c also be used for direct reading when the results can automatically recorded.

PRINCIPLE

The basic system is shown in the block diagram (Fig. . The oxy-hydrogen flame is first fed with a blank soluti As soon as atomization commences, a relay in the atomiz switch circuit comes into operation and the power out voltage charges a capacitor C_1 in the integrating circuit t voltage V. Next a sample is fed into the flame, caus another capacitor C_2 in the integrating circuit to charge t

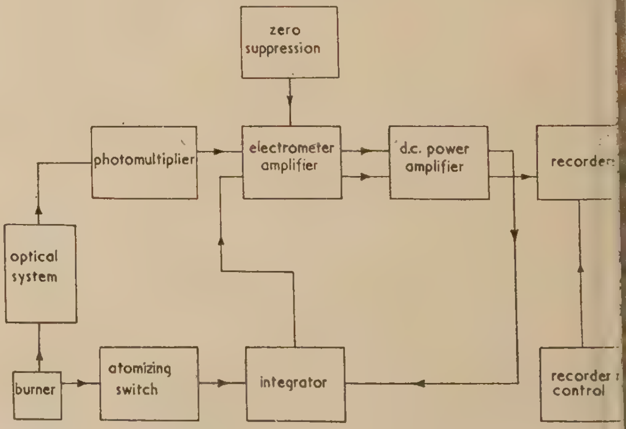

Fig. 1. Block diagram of ultra-micro flame spectrophotometer

ltage $V + dV$. The two capacitors are now discharged in position, causing a voltage $dV/2$ to appear across the ototube load. The discharging voltage is amplified again d its discharge followed automatically to a known arbitary vel on a recorder. Thus a calibration graph of amount ment against time of discharge is constructed using andards; the unknowns are calculable from this graph.

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* This instrument is the subject of British Patent Application No. 1240/58, the rights in which have been assigned to the National Research Development Corporation, 1 Tilney Street, London, W.1.

DETAILS OF APPARATUS

A Beckman DU flame spectrophotometer with a photoultiplier attachment was used with the following modiations and additions.

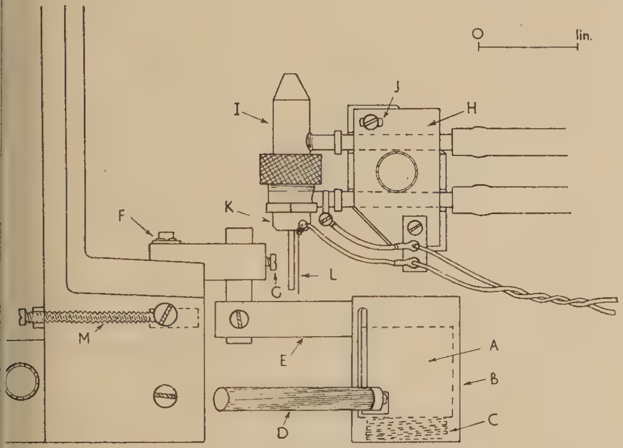

Fig. 2. Diagram of sample holder and modified Beckman burner

Modifications to burner housing. The mechanism for olding the sample was redesigned as shown in Fig. 2, the hole assembly being constructed of brass. The cup ositioner B can be moved horizontally into the burner ousing, a screw stop M ensuring accurate positioning of the p under the burner capillary. The cup holder A can be ised by the handle D, thus releasing the spring C, and rcing the handle to the top of the slot. Screw G operates m E, causing the platinum wire L to just touch the bottom f the cup. The cup holder base was machined so as to ccommodate both the micro-cups and the 5 ml. beakers riginally used by the Beckman flame spectrophotometer. he glass micro-cups held 100 μl. and were treated with C 1107 silicone fluid (by Midland Silicones Ltd.) to reduce rface tension effects.

The burner and its mounting were modified as follows to able operation of the atomizing switch. The metallic ounting block was replaced by an ebonite block H to sulate the burner from the housing. It was found of dvantage to make a channel J for the upper locating pin, nce this enabled the burner to be swivelled on either side f the vertical and facilitated its optical alinement. A small ound ebonite block K was fixed to the burner base and a iece of platinum wire L attached; this projected $\frac{1}{32}$ in. elow the burner capillary. The burner capillary was in ectrical connexion with the rest of the burner I, and acted one electrode with the platinum wire L as the other. ires were attached to these electrodes and taken to the id cathode input of the atomizing switch valve.

Wavelength and dark current controls. The wavelength ob was replaced by a 6 in. metal arm to facilitate accurate tting of the wavelength with narrow slit widths. The arm was detachable to enable rotation of the drum near to the desired setting, when final adjustment could be obtained by means of the arm and an adjustable stop attached to a bracket fixed on the monochromator housing. The dark current control was operated by means of a 3 ft flexible drive, because it was remote from the rest of the controls and switches. The drive was attached to the dark current helipot spindle, and a dial was also fitted to indicate its setting.

THE SPECTROPHOTOMETER CIRCUITS AND MODIFICATIONS

Beckman electrical circuits. The bottom half (below the dotted line) of the complete circuit diagram (Fig. 3) shows the circuitry of the modified Beckman instrument. In addition to this the modified instrument includes the photomultiplier sensitivity switch S_1, the photomultiplier supply batteries B_1 and B_2, and the signal reversing switch S_4.

The original instrument consisted of the photomultiplier V_1, the red photocell V_2, the electrometer and amplifier valves V_3 and V_4 and their associated circuitry (see also Beavers,(7) and the Beckman instruction manual 305A, 1954). The photomultiplier current was measured by balancing the voltage drop across the photomultiplier load resistor selected by S_9 against the voltage across R_{32} (the transmission dial) with the aid of the milliameter M and the action of the amplifiers. A variable voltage controlled by R_{18} and S_5 was used to back off the photomultiplier dark current and the signal produced by the flame background. Switch S_7 selected either the photomultiplier or the red photocell, whilst S_{10} was coupled with a shutter which, in the "off" position, prevented light from reaching the phototubes and was used for dark current compensation. The resistive network R_{30}–R_{37} consisted of the sensitivity control R_{37}, which together with R_{36} controls the voltage across the transmission dial R_{32}, and R_{30} and R_{31}, which were chosen to give a 10 : 1 ratio (910 + 91 Ω) to provide a tenfold extended scale for R_{32}. Switch S_{12}, which has four positions (off, check, 1·0 and 0·1), controlled the filament heating of V_3 and V_4, provided the correct condition for balancing the voltage across R_{32} for 100% transmission without the need to set it for each reading, and finally provided normal and extended scales on which to balance the signal.

Modifications to Beckman DU spectrophotometer electrical circuits. The sensitivity of the Beckman photomultiplier was increased by raising the supply voltage from 600 to 900 V. Instability was reduced by changing all the wiring of the Beckman photomultiplier circuit for earthed screened leads. New switches S_4, S_6 and S_8 were incorporated in the Beckman circuit. Operation of S_4 enabled a reversible potential difference to be applied across the anode load of V_4. In one position of this switch a Pye Scalamp galvanometer type 7903/S can be used in conjunction with a type X17, two-second pen speed, Honeywell Brown recorder, for integrating or direct reading purposes. The other position brings the original balancing milliammeter into circuit and enables the Beckman DU spectrophotometer to be used for absorption measurements or normal flame spectrophotometry. Switch S_8 was incorporated in order to reverse the polarity of the zero suppression battery B_3; thus a complete range of backing-off voltages from +7·5 to −7·5 V is possible. The three-position switch S_6 can be used to charge or discharge the integrating capacitors C_1 and C_2, or for direct reading and automatic recording.

Additional circuits to the Beckman DU spectrophotometer. The integrating circuit and its switching, the recorder control

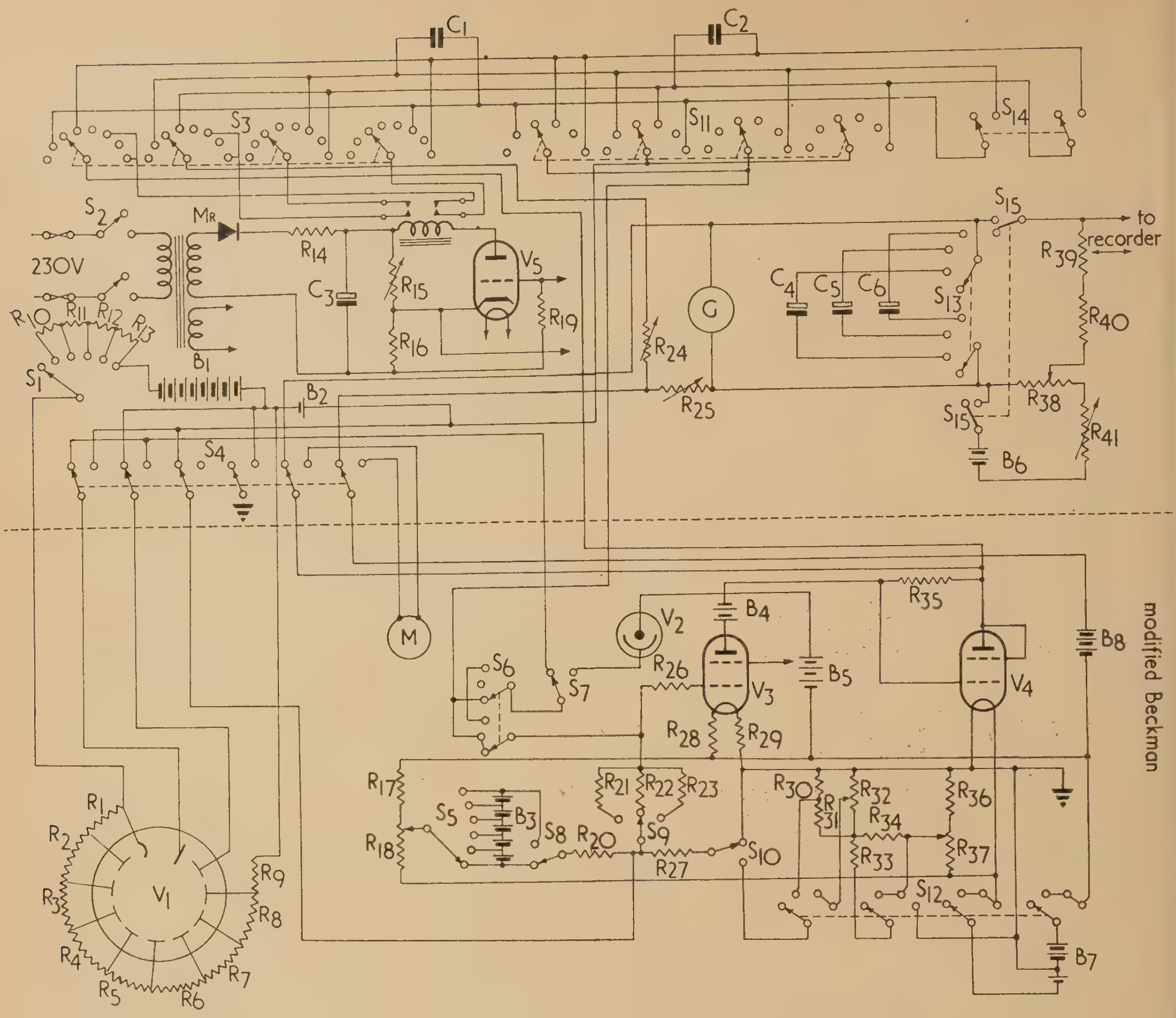
C1
C2
S3
S11
S14
S15
to recorder
S2
MR
230V
R14
R10
R11
R12
R13
C3
R15
V5
R19
R16
B1
S1
B2
G
R24
R25
C4
C5
C6
S13
R39
R40
R38
R41
B6
S4
M
V2
B4
R35
B8
modified Beckman
S6
S7
R26
V3
B5
V4
R28
R29
R17
R21
R22
R23
R30
R31
R32
R34
R36
S5
B3
S8
R20
S9
S10
R33
R37
R18
R27
S12
B7
R1
R2
R3
V1
R9
R8
R4
R5
R6
R7

Fig. 3. Circuit diagram of ultra-micro flame spectrophotometer

R_1–R_9 = 330 kΩ
R_{10} = 510 kΩ
R_{11}, R_{12} = 680 kΩ
R_{13} = 750 kΩ
R_{14} = 10 kΩ, 4 W
R_{15} = 500 kΩ
R_{16} = 10 kΩ
R_{17} = 167 Ω
R_{18} = 334 Ω
R_{19}, R_{20} = 1 MΩ
R_{21} = 5 MΩ
R_{22} = 22 MΩ
R_{23} = 10 kMΩ

R_{24} = 5 MΩ
R_{25} = 500 kΩ
R_{26} = 22 MΩ
R_{27} = 150 kΩ
R_{28} = 47 Ω
R_{29} = 39 Ω
R_{30} = 909 Ω
R_{31} = 120 Ω
R_{32} = 100 Ω
R_{33} = 10·1 Ω
R_{34} = 91 Ω
R_{35} = 100 MΩ
R_{36} = 25 Ω

R_{37} = 200 Ω
R_{38} = 50 Ω
R_{39} = 1 kΩ
R_{40} = 10 kΩ
R_{41} = 1 kΩ

C_1, C_2 = 8 μF (paper), 25 V
C_3 = 16 μF, 350 V
C_4 = 1000 μF, 25 V
C_5 = 2500 μF, 25 V
C_6 = 5000 μF, 25 V

B_1 = 810 V
B_2 = 90 V

B_3 = 7·5 V
B_4, B_5 = 15 V
B_6 = 4·5 V
B_7 = 6 V (accumulator)
B_8 = 22·5 V

MR = 20 mA

V_1 = RCA 931A (IP28)
V_2 = red photocell (Beckman)
V_3 = Beckman 32 E
V_4 = Beckman type 30
V_5 = 6C4

and atomizing switch circuits were all housed in a separate cabinet. All the new switches, except S_6 which was attached to the spectrophotometer, were fastened on to a front Perspex panel. External connexions to the spectrophotometer and recorder were made by the use of earthed screened leads connected to insulated terminals. This unit also contained the photomultiplier switch S_1, the zero suppression switch S_5, the photomultiplier supply batteries and the Beckman C batteries (B_3, B_4, B_5 and B_8).

For operation as an ultra-micro flame spectrophotometer, R_{25} was adjusted to 10 kΩ; this gave the maximum power output across this load. The integrating capacitors C_1 and C_2 are 8 μF capacitance matched, low leakage, 25 V working Dubilier paper type. They are charged through R_{24}, which was adjusted so that only about 20% of the applied potential difference from V_4 was reached after complete atomization of the solution, thus ensuring that the dV/dt did not dev unduly from linearity. The time required for the comp atomization of 100 μl. volumes when using a medium b capillary burner with 15 lb/in.^{2} oxygen and 3 lb/in.^{2} hydro was 3·5 s in the authors' experiments, so R_{24} was kep 2 MΩ. The multiple switches S_3 and S_{11} enable the capaci C_1, C_2 to be charged either directly from the photomultip which has been found useful for calibration purposes, from the output of V_4. These switches permit the capacit to be charged either manually or electronically and to discharged in opposition. Switch S_{14} shorts out capacitors, thus ensuring that no charge remains before next reading is taken. The input of V_4 must always controlled by R_{18} and S_5, so that the valve is operating the linear part of its response curve, and consequently always draws a little current. A backing-off circuit, wh ısists of B_6, R_{38} and R_{41}, enables the recorder output to brought to zero, even though this current is drawn by V_4. 'e potential divider R_{39} and R_{40} enables the voltage ›duced for charging the capacitors to be attenuated in ler to operate the 2 mV input recorder. The atomizing itch consists of V_5 with a 300 Ω relay in its anode circuit; $_5$ is adjusted so that this valve is not conducting. Atomiz- ; the sample shorts the grid cathode input causing V_5 to nduct, the relay closes and the integrating capacitors can arge. When the instrument is not used with the integrating cuit, it may be used as a direct-reading device, and for this rpose S_6 is switched to position 3. The signal can then be tomatically recorded or read directly on the galvanometer. choice of electrolytic capacitors C_4, C_5 and C_6 provides itable damping for the galvanometer readings.

OPERATION

A detailed series of directions for the operation of the ;trument as an ultra-micro flame spectrophotometer, or as direct-recording instrument or absorptiometer are given ewhere.(8)

The ultra-micro flame spectrophotometer was set up so as ensure that the output of V_4 was just operating on the ear part of its response curve, when the blank solution 5% acetone, 5% hydrogen chloride and 10% water) was pirated into the flame, and R_{25} was set at 10 kΩ. The corder was then set up so that there was linearity of deflex- ı, and so that the maximum anode current of V_4 produced full-scale reading. The essential steps of the rest of the erations were as follows: R_{24} was set at 2 MΩ, 100 μl. of ank solution (held in a siliconed micro-cup) was fed into e oxy-hydrogen flame, and S_3 switched so that the omizing switch would automatically allow capacitor C_1 charge whilst the solution was aspirated. Next, 100 μl. a standard or sample solution was introduced into another iconed micro-cup and S_3 arranged to charge capacitor C_2. vitches S_6 and S_{11} were then operated to discharge the pacitors in opposition, and the time taken for the charge fall to some set arbitary level on the recorder was calculated.

Operation as a direct-reading instrument is very much npler than above. R_{25} was set at 0 Ω, and S_6, the capacitor ntrol switch, was switched to position 3 (direct reading). ıe setting-up procedure was similar to that for integration, ıt in this case R_{39} was adjusted to give maximum deflexion ı the recorder for the most concentrated standard. ımples were introduced in either the original Beckman cups the micro-cups, and the results automatically recorded.

To operate as an absorptiometer, or for normal Beckman ıme spectrophotometry, the signal reversing switch S_4 was t to operate the milliameter M_1 and the polarity of the ro suppression battery reversed by S_8.

PERFORMANCE

The basic requirement for this work was to determine 50 μmg magnesium and to keep the volume of aspirated aterial small. The atomizing switch was introduced ›cause it was found difficult to time accurately the short terval required to atomize a 100 μl. volume. From the llowing considerations, total atomization of a standard ›lume has many advantages over partial aspiration for a finite time interval. The signal strength changes in direct oportion to the atomization rate; the time taken for a andard volume to atomize is also directly proportional to is rate. Therefore, if the atomization rate drops, a longer time is taken for a given volume of liquid to atomize, but at the same time the signal strength decreases proportionately. On the other hand, an increase in rate means a shorter atomization time with an increased signal. Thus, if the total signal from a standard volume is integrated, variations in the rate of aspiration do not affect the reading. Again, automatic compensation is made for evaporation from aqueous solutions; here the volume decrease causes a proportional increase in the signal.

Because the samples were in acetone and some evaporation occurred during the time of sampling and aspiration, as much as ±5% error was found. This was reduced to ±2% by atomizing immediately after removing the sample from a closed vessel. Normally evaporation would not cause such errors, but in this case, when acetone evaporates, differences are caused owing to its enhancing effects.

The sensitivity of the methods when the instrument is used with the enhancing solvent is greater than any other hitherto described. Previous attention to ultra-micro determinations of inorganic ions in biological fluids has been devoted almost entirely to sodium and potassium, the most sensitive of which is the determination of sodium by Bott.(5) This worker used a modification of the ultra-micro apparatus devised by Ramsay(4) and others, and was able to detect down to $2 \cdot 5 \times 10^{-12}$ g of sodium; the present instrument will detect down to 3×10^{-13} g of sodium. The instrument, however, has been used mainly to determine magnesium in biological fluids, and its application for this purpose will be described in another paper. The instrument can determine 1–10 μmg of magnesium with an accuracy of ±5%; a typical calibration curve is shown in Fig. 4. The previous most sensitive method for magnesium was the colorimetric method of Mann and Yoe,(9) which is 500 times less sensitive than the present procedure.

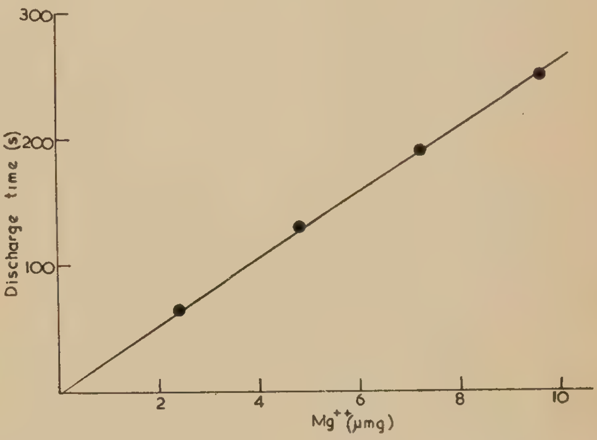

Fig. 4. Typical calibration graph for magnesium standards

The magnesium standards were made up in physiological saline. 0·1 ml. samples were atomized in 3·75 s. The instrument was used with the following settings: Sensitivity position 5 (full); hydrogen = 3 lb/in.^{2}; oxygen = 15 lb/in.^{2}; anode load = 10 kΩ; CR charge value = 14·6 s; phototube load resistor 22 MΩ for charge and discharge; zero suppression battery position 4; slit width 0·03 mm; magnesium measured at 2854 λ.

The instrument can also be used as a direct-recording device without the integrating circuit. Quantities of 0·1–1·0 μg of magnesium and calcium in liver mitochondrial preparations and cerebrospinal fluid can be determined with an accuracy of ±3%. Sodium concentrations between the range 1–1·2 parts per million were automatically recorded with an accuracy of ±2%.

ACKNOWLEDGEMENTS

Thanks are expressed to Prof. Sir Hans Krebs and Dr. D. E. Hughes for their interest in this work, and also to Mr. A. Renshaw for his assistance. This work was aided by a grant from the Rockefeller Foundation.

REFERENCES

(1) Barnes, R. B., Richardson, D., Berry, J. W., and Hood, R. L. *Industr. Engng Chem.* (Anal. ed.), **17**, p. 605 (1945).

(2) Belke, J., and Dierkesmann, A. *Arch. f. exp. Path* *Pharm.*, **205**, p. 629 (1948).

(3) Domingo, W. R., and Kylne, W. *Biochem. J.*, p. 400 (1949).

(4) Ramsay, J. A., and Brown, R. H. J. *J. Exper. Biol.*, p. 1 (1953).

(5) Bott, P. A. *Am. Fed. Proceedings, Exp. Biol.*, **16**, 1, p. (1957).

(6) Cary, H. H., and Beckman, A. O. *J. Opt. Soc. A* **31**, p. 682 (1941).

(7) Beavers, G. H. *Photoelec Spectro Gp. Bull.*, **2**, p. (1950).

(8) Exley, D. D. Phil. Thesis, Oxford (1958).

(9) Mann, C. K., and Yoe, J. H. *Anal. Chem.*, **28**, p. (1956).

The emission of light from electric discharges of microsecond durations in gases at atmospheric pressure

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This paper compares the performance of four types of spark discharge, widely used(1–4) as light sources of high intensity and short duration. Using the same capacitor and stored energy, electrical and light emission waveforms, and integrated spectra, were recorded for each type of discharge. Air sparks, both free and guided across the surface of an insulator, and argon sparks both within a jet of argon, and enclosed by a quartz capillary tube, were studied in this manner. The results are discussed in terms of the possible applications in fast photography and the photo-irradiation of materials. Particular attention is drawn to the novel properties of the discharge within an argon jet, as this affords a source of high positional stability and repeatability of performance, while retaining the high intensity and small size of other discharges.

INTRODUCTION

In this laboratory there is on hand a continuous programme of investigation into the behaviour of crystals of unstable compounds. In particular the burning and detonation of a number of explosive materials have been studied under a variety of experimental conditions.(5) The techniques of high-speed photomicrography have been applied successfully(6) in these investigations, and have resulted in the development of a number of camera systems,(7) potentially of wide application. Electric discharges have been used as illuminants in conjunction with these cameras and have proved extremely versatile. Within wide limits, it is now possible to design electronic flashgear to provide an intensity and duration of light emission to suit the requirements of the experimental subject and the camera system employed.(8) Additionally, electric discharges have been used for photostimulation of the same materials,(9) conveniently affording high irradiation intensities over the band of wavelengths from 2000 Å to beyond 7000 Å. It can be seen that it necessarily becomes important to know as much as possible about the electric and emissive properties of discharges, in order to achieve an optimum result in any given application. Since particular applications differ widely, there will be a considerable diversity of information required, before a discharge system can be chosen and designed.

To meet some of these requirements, we have begun systematic investigation into the behaviour of two sorts electric discharges. In the first, the emission is maintain at a sensibly constant level, for a period which is much long than the rise and fall times to and from this level. T results of some work upon this system have already be published.(8, 10) In the second, it is intended that the emissi should occupy as short a period as possible. In the mic second and submicrosecond region, such discharges norma consist of a short rise and longer fall time, with a relativ small region where the emission is sensibly constant. It the purpose of this paper principally to outline and disc the results of some investigations into this second type discharge.

SELECTION OF DISCHARGES FOR STUDY

The list of possible applications of short electric dischar in photography alone is a formidable one, including recordi by both reflected and transmitted light, silhouette, schlier and interferometric work, to which must be added the u in photochemistry and photophysics already mention Design for these applications should involve foreknowle of at least the luminance, forward illuminating power, spect distribution, efficiency, duration, peak power, rates of r and fall of emission, and size of the discharge considered a source. Since all these quantities vary non-linearly w changes in the construction of the storage capacitor and t discharge gap and the type and pressure of the gas in t

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, the problem of compiling adequate information is siderable. It is clearly desirable initially to maintain stant some of the independent variables; e.g. a single e of storage capacitor may be used, while investigating nges in the discharge gap and the gas. The variations in discharge gap may be arranged so that the gap may ime any of several typical and widely employed con- rations, e.g. unconfined discharge, discharge confined by ilica capillary; and discharge across the surface of an ılator. The gases used may be initially at atmospheric perature and pressure and need include only representa- gases of sensibly differing properties.

DISCHARGE APPARATUS

he experiments described below were therefore undertaken h a single capacitor of nominal capacitance 0·1 μF, structed by Messrs. Dubilier to special order for repetitive h working at fifty flashes per second. Under these ditions it was rated at 7000 V, but under the conditions the experiments where flashes were recorded singly at ervals of several seconds, a higher rating might be appro- ate. An X-radiograph of the capacitor (Fig. 1) showed t the lead-out wires might represent a considerable con- bution to the inductance of the discharge circuit. The minal insulators and lid of the capacitor were therefore noved* and replaced by a Perspex lid with the discharge gap mounted upon it (Fig. 2). The electrodes consisted of stainless steel rods with hemispherical ends, threaded 0 B.A. These screwed through brass terminal blocks to which the lead out wires were soft-soldered. The length of the gap could therefore be adjusted readily, and substitution of electrodes with axial holes, drilled for the insertion of trigger electrodes and/or the passage of gases, was a simple matter. A silica capillary tube (Fig. 3) could be introduced between the electrodes, and with its ends worked concave to the same radius as the electrodes provided an almost gastight chamber. For surface discharge experiments, a trigger electrode was embedded in Araldite (by Aero Research Ltd.) which, after suitable machining (Fig. 4), could be placed across the gap to "guide"(11, 12) the discharge along a suitable path. While

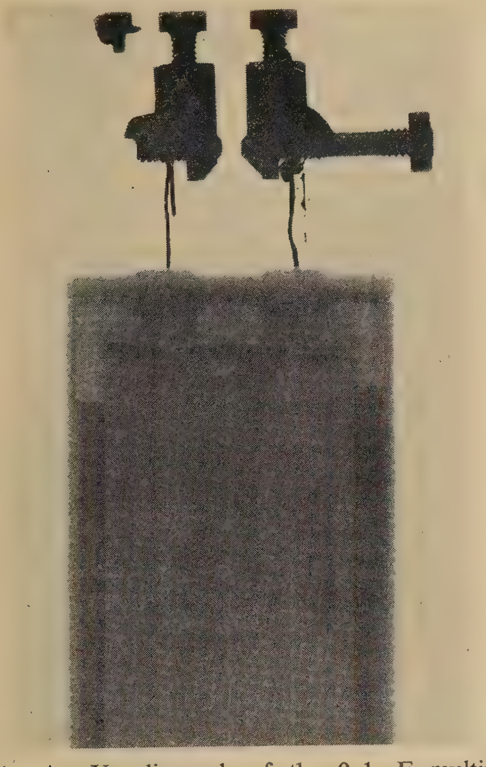

Fig. 1. An X-radiograph of the 0·1 μF multipack capacitor used in the experiments described. It can be seen that the area enclosed by the lead out wires will contribute not insignificantly to the inductance of the discharge circuit

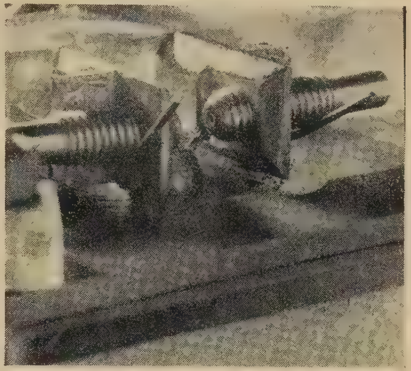

Fig. 2. The discharge gap used in the experiments shown mounted upon the capacitor of Fig. 1, after removal of the terminal bushes and top plate. The end of an axial hole, for argon injection, is visible in one electrode. The other electrode normally carries a trigger electrode, supported axially within a similar hole by means of a ceramic sleeve. Both electrodes are screwed for ease of adjustment to suitable gap lengths in the range 0–10 mm

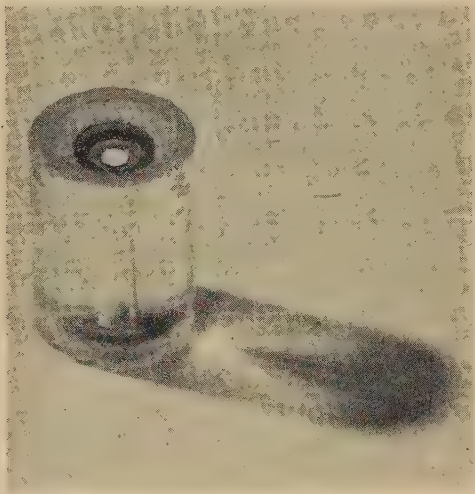

Fig. 3. A length of silica capillary tube of 1 mm internal diameter with the ends ground concave. The capillary may be gripped between the ends of a pair of discharge electrodes, which have hemispherical ends of the same curvature

the unconfined and capillary discharges triggered readily from a low energy (10 mJ) 13 kV trigger pulse, it was necessary to supply a 50 kV (100 mJ) pulse to the trigger electrode of the "guided" discharge; this was obtained from an encapsulated pulse transformer manufactured by Messrs. Wayne Kerr Ltd.

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* While this treatment is likely to reduce the life of the capacitor, e to absorption of atmospheric water in the dielectric oil, this rticular unit has survived some hundreds of single discharges r a period of a year.

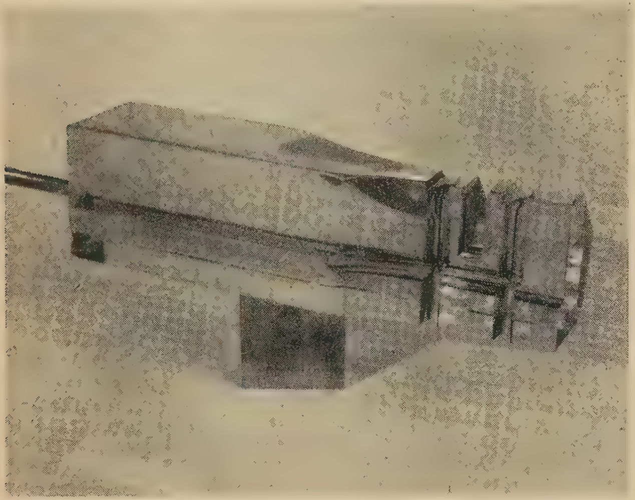


Fig. 4. The guided discharge surface used in the experiments. An F-shaped trigger electrode has been embedded in Araldite *D* casting resin, and the latter subsequently machined to a suitable shape. In particular an F-shaped groove cut in the surface allows the discharge to follow the shape of the head of the embedded electrode, while a slot between the tongues of the F prevents the discharge from taking a short direct path across the surface

These three discharge gaps were studied first in air and then, where appropriate, in an atmosphere of commercial argon.

While this represents a small section of the possible choice of variables, the discharges chosen are relatively easy to set up, simple to reproduce, and already widely used. Despite this, however, there is yet little literature describing their properties comparatively.

SELECTION OF PROPERTIES FOR RECORDING

While it is possible to record and analyse most of the parameters associated with the dissipation of power in and emission of light from a discharge, not all of these can be obtained directly or in a simple manner. It is not easy for instance, with a microsecond discharge, to make an analysis of the discharge current through the gap, without modifying the discharge circuit to accommodate a monitoring resistor. It is, however, possible to monitor the first derivative of this current by recording the voltage across a loop of wire inductively coupled to the discharge circuit. This has afforded useful information,(13) and it would be possible to integrate this waveform electronically if it were ever important that the current waveform be studied.

Similarly it is easy to record the spectral emission of the discharge integrated over the whole of the duration of the flash. This can be done photographically, with the aid of a suitable spectrograph. It is little more difficult to monitor the emission of light as a function of time over the range of wavelengths to which a photocell is sensitive. Neither these approaches separately affords complete information the emissive behaviour of the discharge.

MONITORING APPARATUS

Integrated discharge spectra were obtained by imaging discharge, magnified three times by means of a quartz l across the slit of a large quartz/glass spectrograph (by Hi and Watts Ltd.). The low relative aperture of this instrum necessitated the superimposition of eight to sixteen flas in order to achieve a useful image density on the long ra spectrum plates employed (by Ilford Ltd.). In order, th fore, to ensure that the section of the discharge viewed not wander from flash to flash, the argon "jet" technique described in Appendix I, was employed. The high resolu of this spectrograph enabled metal emission lines to readily distinguished from the broader gas lines and ens ready identification of the latter against an iron calibra spectrum. Photographic emulsions of similar sensitivity the blue but increased red sensitivity, e.g. type HP3 Ilford Ltd.), were used occasionally to verify the presenc emission in the red and near infra-red regions. The spec graph was normally set to record the region from 2900 Å 6500 Å.

The emission as a function of time was monitored in 3150 Å to 5600 Å region by means of a type 929 vac photocell (by Radio Corporation of America Ltd.). voltage developed across a 1000 Ω resistor, in series with photocell, was displayed against a linear sweep on a synchroscope,(15) and photographed on to Ilford fast g sensitive recording film, using a type C. 100 camera J. Langham Thompson Ltd.) fitted with a *f*/1 lens Wray (Optical Works) Ltd.]. The photocell was ru 1700 V to avoid space charge saturation effects and calibrated against a standardized tungsten filament la The estimated time constant of this arrangement sufficiently low (55 mμs) to avoid perceptible degradation the waveforms recorded.

The first derivative of the discharge current, obtained means of the inductive loop already mentioned, was fed terminated r.f. cable to a type WM5 oscilloscope (by Elec and Musical Industries Ltd.), and the waveforms ph graphed as described above for the emission wavefo The limiting time constant of this arrangement was estima to be 20 mμs, which may account for the finite rate of of the first excursions of, for instance, the waveforms *a* *b* in Fig. 6.

EXPERIMENTAL RESULTS

(i) *Spectra.* In Fig. 5 are shown the emission spectra the unconfined discharges in air and in argon. Meas ments on the plates showed that the discharges expande about 2 mm diameter during the period of high emissio light. The air spectrum is sensibly that of nitrogen, tho a few oxygen lines appear faintly. Metal lines appear, increase in strength and number as the discharge sec viewed is increasingly closer to the electrodes. All the lines are broad and little structure appears at wavelen less than 3900 Å. In the argon spectrum again consider gas line structure is present at wavelengths greater 3700 Å but close examination reveals only two sharp li neither of which appear to be iron emission lines. majority of the gas lines fit the listed wavelengths of argon "blue" spectrum. If the diameter of the axial ho the electrode, through which the argon was blown into

), was reduced below 0·5 mm, nitrogen lines began to ppear. Confinement of the argon discharge by means of 1 mm bore silica capillary tube resulted in the virtual appearance of the gas line emission spectra. The exposed tes (not illustrated) showed little more than a structureless ntinuum.

(ii) *Electrical waveforms.* In Fig. 6 appear the first derivatives, with respect to time, of the discharge currents obtained in the three forms of gap. *a* is that of an unconfined argon discharge across a 8 mm gap. It differs insignificantly from that across a 4 mm gap in air, and it can be seen that the discharge circuit is considerably less than critically damped by the dissipation in the discharge and in circuit losses. When the argon discharge was confined by means of a silica capillary tube of 1 mm internal diameter the circuit became more heavily damped, and *b* shows the damping to have been only a little less than critical. Comparison may be made between *b* (and also *c* and *d*) and the waveforms appropriate to a discharge circuit incorporating dissipative elements of constant resistance. Unlike discharges at low gas pressures where equilibrium conditions may be considerably influenced by the walls of the discharge vessel, these relatively unconfined discharges at atmospheric pressure appear to offer an impedance varying considerably during the discharge. Additionally it was discovered that the confined discharge would function as a triggered discharge over a range of initial electric field strengths in the gap of about 2 : 1. For the unconfined discharge a ratio of about 1·4 : 1 was more typical. In *c* is shown the waveform of a guided surface discharge, over an air path length of 32 mm. Its resemblance to *b* is striking. In *d*, the path length has been increased to 51 mm, the maximum gap that could be crossed consistently under the stated experimental conditions (storage capacitor charged to 7 kV, and 100 mJ trigger pulse obtained from 50 kV transformer). The discharge current here became non-oscillatory, and also a kink has appeared in the leading edge of the *di/dt* waveform. This detail is lost in *e* which shows an identical waveform, brightness modulated by means of a 5 Mc/s calibration signal.

(iii) *Emission waveforms.* These are shown in Fig. 7, and some parameters calculated from measurements on these

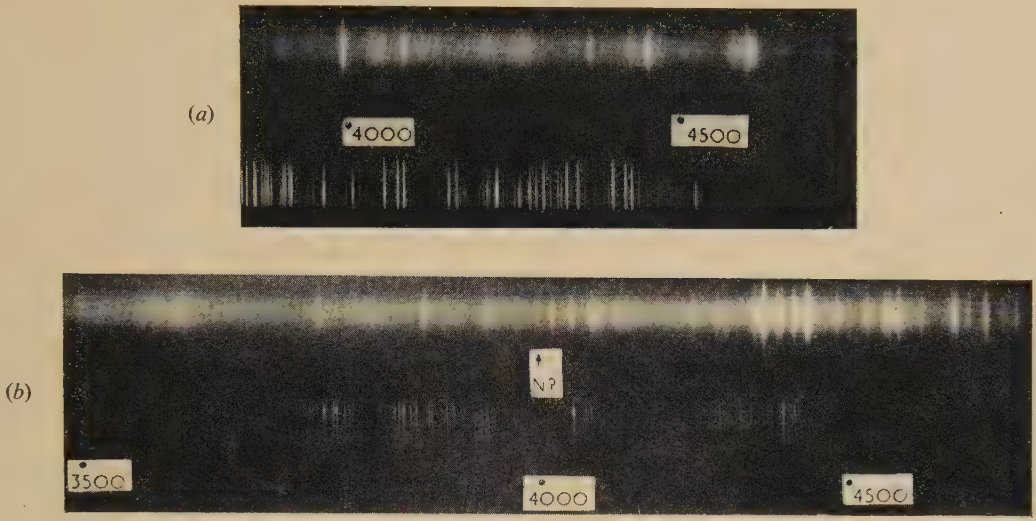
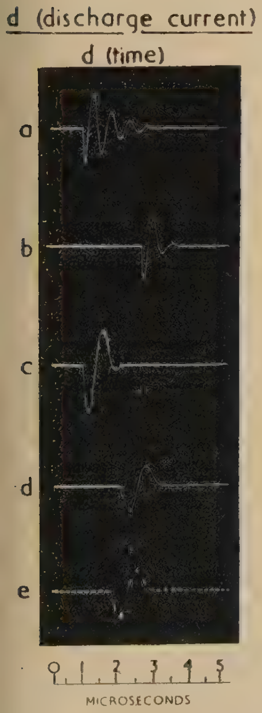


Fig. 5. Spectra of the 2·5 Joule discharge through air (*a*) and through argon (*b*) in the visible and near ultra-violet. A continuum, and considerable gas line emission, appears in both cases. The spectrograph slit, set at 0·05 mm width, viewed a section of the discharge at right angles to the electrode axis. The sharp lines in the air spectrum are principally iron emission lines, as may be seen by comparing them with the iron calibration spectrum recorded on the same plate. The argon spectrum contains only two sharp lines, neither apparently from the iron spectrum. In addition the 3995 Å nitrogen line appears faintly, as the argon jet within which the discharge occurred was less than 0·5 mm diameter. The effective diameter of the discharge was several times greater than this, namely about 2 mm diameter



(*a*) 8 mm long argon discharge; (*b*) 8 mm long argon discharge in 1 mm diameter silica capillary tube; (*c*) 32 mm path guided discharge across Araldite surface; (*d*) 51 mm path guided discharge; (*e*) 51 mm path guided discharge with 5 Mc/s calibration modulation on the oscilloscope trace. The traces have been reproduced on the same timescale but they have no common scale in the vertical direction. Long triggering delays are apparent in (*c*), (*d*) and occasionally (*b*).

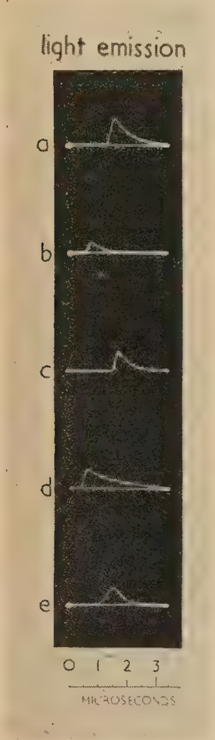
Fig. 6. Waveforms of the first derivatives of the discharge currents

Table 1. *Parameters calculated from measurements on emission waveforms shown in Fig. 7*

	A	*B*	*C*	*D*	*E*	*F*	*G*
	Luminance (*Mcd/cm*^{2})	*Forward illuminating power* (*Mcd*)	*Integrated forward emission* (*cd s*)	*Efficiency* (*cd/W*)	*Effective duration* (*C/B*) (μs)	*Duration at 30% of peak level* (μs)	*Total rise ti* (μs)
Air	32	2·5	1·4	0·56	0·56	0·6	0·325
Argon jet	42	6·7	4·9	1·96	0·73	0·9	0·236
Argon in silica capillary	48	4·8	5·7	2·28	1·2	1·5	0·265
Air guided across Araldite	—	4·3	3·3	1·32	0·77	0·8	0·620

No corrections have been applied for the differences in spectral emission between the various discharges and the tungsten calibrat lamp, since photometric determinations in terms of, for instance, visual units are not of great value in the likely applications of s discharges. For particular applications it may be more profitable to derive a comparison the results of which can be weighted subseque in terms of the photonic sensitivity either of the particular photographic emulsions or the particular photocells intended to be u However, the values quoted in the table may be used conveniently for preliminary calculations on projected systems, with ei approximate weighting or none at all.

waveforms are shown in Table 1. The highest forward illuminating power is afforded by the 8 mm unconfined discharge in argon *a*. Air *b* differs little in luminance but since the gap that can be crossed is only half the length, the illuminating power is also less by about this factor. The rise and fall times are similar for these two gases as can be seen by comparing *a* with *c*, for which the photocell had been moved closer to the discharge. In *d*, which is of the confined discharge in argon, a relatively long fall time is apparent and the table shows that this confers upon the silica capillary discharge a relatively high efficiency of conversion of electrical energy into light. The 51 mm path guided discharge is alone in having a nearly symmetrical waveform *e*. It shows a greater forward candlepower and a higher efficiency than the unconfined discharge in air and falls only a little short of the emission of the unconfined argon discharge.



(*a*) 8 mm long argon discharge; (*b*) 4 mm long air discharge; (*c*) 4 mm long air discharge at closer range; (*d*) 8 mm long argon discharge in 1 mm internal diameter silica capillary tube; (*e*) 51 mm path guided discharge across Araldite surface. The traces are fairly similar but (*d*) appears remarkable by reason of its long tail, while (*e*) has an unusually long risetime, and indeed is nearly symmetrical.

Fig. 7. Light emission waveforms from the four discharges

DISCUSSION OF RESULTS

Applications involving high peak emission for a short ti within a specified band of wavelengths may find the h efficiency of the silica capillary discharge in argon of val The structureless continuum available may allow eq energy irradiation of substances in chosen wavelength ban without superimposed emission lines. The unconfined arg discharge will afford higher peak emission at the waveleng of some prominent emission lines, should this be preferab This property will be of use also in high-speed interfe metry; it can be seen from the spectra that the argon dischar filtered by means of a narrow band filter centred on, instance, 4345 Å would provide a useful source. At a som what lower intensity, the 3995 Å nitrogen line of the discharge would be similarly useful. It would seem that maximum integrated emission there is little advantag selecting the regions around 4505 and 4360 Å where the continuum and emission lines are noticeably feeble.

Any application requiring that the electrical energy completely dissipated within the shortest possible time c make use of either the silica capillary or the guided surfa discharge. It is unfortunate that both these metho necessitate the proximity to the discharge of materials relatively large thermal capacity, since the energy absorb in this way might otherwise be contributing towards t brightness of the discharge. It is reasonable to suppose th an increase of the gap length × gas pressure product, pr senting a higher arc voltage drop across the gap, shou afford the high discharge resistance required(16) without su concomitant disadvantages. However, it is relatively le easy to strike such an arc without considerable increase the energy of the triggering mechanism. This may w prove a fruitful field for further experiment. Additionally, would be desirable to utilize a capacitor having a still high figure of merit (see Appendix II), since this would reduce t required increment of this product, for the same eventu result. Higher figures of merit are currently possible,(17, 1 but the increase that would provide a discharge circuit be suited to short unconfined discharges does not yet seem be in sight.

High-speed photomicrography requires sources of hig specific brilliance. Again the argon in silica capillary tu affords the highest peak values of this parameter. For a such application where a shorter emission time is desirab the unconfined argon or air discharges, at about thre quarters of the luminance, may be preferable. The mo general needs of high-speed photography centre on sources high peak forward candlepower, where there is a choi between argon confined or unconfined, and the guided a

:harge. The choice here may partly depend upon whether short duration of the unconfined discharges is preferred he higher efficiency of the confined discharge, or *vice versa*.

CONCLUSIONS

The relative performance of four different gas discharge tems have been determined by experiment. Their merits /e been discussed in terms of their suitability as light irces for high-speed photography and photo-irradiation. general it appears that substantial increases in forward minating power may be expected when a simple air gap charge is replaced by either a similar discharge in argon h or without a silica capillary discharge tube, or by a ded discharge over an Araldite surface. The silica oillary also imparts a high luminance and a high efficiency the discharge, but at the cost of increasing the time ration, principally that of the tail of the emission. In lition the gas line emission spectrum no longer appears, t is replaced by a continuum. The results obtained also ggest useful avenues for further improvements in discharge hniques; in particular, those of (*a*) discharge circuits ssessing higher figures of merit, and (*b*) discharge gaps of her length × pressure products.

Additionally, the work has revealed(14) that a low velocity eam of argon passing axially between the electrodes of a charge gap is not only:

(*a*) Substantially equivalent to provision for complete immersion of the discharge circuit within the gas, but also confers the following useful properties:

(*b*) The discharge always travels within the argon stream. Hence it is repeatably straight and occupies the same spatial position.

(*c*) The remainder of the apparatus may be designed for the higher dielectric strength of atmospheric air.

(*d*) The consumption of argon may be very low.

ACKNOWLEDGEMENTS

The author gratefully tenders the following acknowledge-ents: to the Dubilier Condenser Co. for constructing ecial capacitors and supplying spare Nitrogol oil; to ayne Kerr Ltd. for the loan of an encapsulated pulse insformer; to G. Hodgson for the X-radiograph of Fig. 1; Dr. J. S. Courtney-Pratt for encouragement in the work d for reading and commenting upon the MS. of this paper; Dr. F. P. Bowden for his continued support; and to the epartment of Scientific and Industrial Research for a grant the laboratory.

REFERENCES

1) CHESTERMAN, W. D. *The Photographic Study of Rapid Events* (Oxford: Clarendon Press, 1951).

2) EDGERTON, H. E., and KILLIAN, J. R. *Flash* (Boston: Branford, 1954).

3) BEESON, E. J. G. *B.T.H. Activities*, **27**, p. 131 (1956); *J. Phot. Sci.*, **1**, p. 90 (1953).

4) MARSHAK, I. S. *3rd International Congress on High Speed Photography*, p. 30 (London: Butterworths Scientific Publications, 1957).

5) BOWDEN, F. P., and YOFFE, A. *The Initiation and Growth of Explosives in Liquids and Solids* (London: Cambridge University Press, 1952).

(6) EVANS, B. L., and YOFFE, A. D. *Proc. Roy. Soc. A*, **238**, p. 325 (1956).

(7) COURTNEY-PRATT, J. S., and THACKERAY, D. P. C. *J. Phot. Sci.*, **5**, p. 32 (1957).

(8) THACKERAY, D. P. C. *3rd International Congress on High Speed Photography*, pp. 21 and 42 (London: Butterworths Scientific Publications, 1957).

(9) COURTNEY-PRATT, J. S., and ROGERS, G. T. *Nature* [*London*], **175**, p. 634 (1955); *2nd O.N.R. Symposium on Detonation, Washington, D.C.*, p. 429 (Washington: U.S. Dept. of Commerce).

(10) COURTNEY-PRATT, J. S., and THACKERAY, D. P. C. *Actes du 2e Congrès International de Photographie et Cinématographie Ultra-Rapide*, p. 163 (Paris: Dunod, 1956).

(11) FAYOLLE, P., and NASLIN, P. *Photographie Instantanée et Cinématographie Ultra-Rapide* (Paris: Editions de la Revue d'Optique, 1950).

(12) TAWIL, E. P. *3rd International Congress on High Speed Photography*, p. 9 (London: Butterworths Scientific Publications, 1957).

(13) HOYT, G. D., and MCCORMICK, W. W. *J. Opt. Soc. Amer.*, **40**, p. 658 (1950).

(14) U.K. Patent Application No. 19640/57, and THACKERAY, D. P. C., *Nature* [*London*], **180**, p. 913 (1957).

(15) THACKERAY, D. P. C. *Electronic Engng*, **27**, p. 397 (1955).

(16) FRÜNGEL, FR. *Optik*, **3**, p. 128 (1948).

(17) BERGLUND, S., *et al.* *Nuclear Instrum.*, **1**, p. 233 (1957).

(18) CLAESSON, S., and LINDQVIST, L. *Arkiv Kemi*, **12**, p. 1 (1957).

APPENDIX I

During some previous work, on spark light sources in optical systems several hundreds of metres in length, it became apparent that the variation in source position from spark to spark inevitably added uncertainty to any measurements made upon the systems. It is difficult and often impossible to reduce this uncertainty to negligible proportions even in smaller systems, especially if the systems contain small pupils and are stigmatic. It is, of course, possible to enclose the discharge within a silica capillary tube, or guide it along the surface of an insulator; while these devices improve the positional stability of the discharge, they usually increase the time duration of the light output, and this may not be wholly desirable.

While experimenting with discharges through argon, which affords higher values of peak illuminating power than air, the following alternative solution was evolved:

If a non-turbulent stream of argon were made to flow from one discharge electrode to the other, the discharge confined itself within the argon stream. It was convenient, as the electrodes were in line, to drill an axial hole in one of them so that argon blown through the hole would travel across the discharge gap and impinge upon the other electrode. If the hole and electrode were suitably shaped, the stream became non-turbulent; the flow rate could then be adjusted to provide a stream velocity suitably greater than any ambient "draughts" in the laboratory. However, as the hole diameter could be reduced to less than half a millimetre before a 2·5 Joule discharge began to ionize the surrounding air appreciably, the consumption of argon was in fact still quite small (in the range 0·1 to 1·0 l./min).

Thus it became possible, with the apparatus described in this paper, to establish a discharge in argon, of shape, size and position that were entirely repeatable from spark to spark. The device is, however, even more versatile, since jets of argon from *both* of two electrodes *not* in line may be arranged to meet, and the discharge will then be of an L or V shape. Additionally, the discharges may be continuous from suitable power supplies, which affords the possibility of directing continuously an ionized stream of gas on to surfaces, or into suitably receptive holes or tubes.

The fundamental mechanism involved, in this preferential ionization of argon in the presence of air, has not yet been studied. However, as the dielectric strength of argon appears to be about half that of air, the effect is perhaps not surprising.

APPENDIX II

A number of different "figures of merit" are applicable to capacitors intended for discharge use. For instance the obtainable peak current is related to $V/\sqrt{L/C}$ where V is the rated capacitor voltage, C its capacitance and L its residual inductance at a frequency $f = 1/2\pi\sqrt{LC}$. Alternatively, the initial rate of rise of current possible may be of greater interest, and this is related to V/L. It is instructive to compare on this basis the capacitor used in the experiments with some others for which information is available.

Table 2. *Figures of merit of typical discharge capacitor*

Capacitor	*V/L (A/s)*	*Source of information*
Dubilier 30 μF at 2·8 kV	$42 \cdot 10^{10}$	Calculated from me urements.
Dubilier 0·1 μF at 7 kV Multipacks	$10 \cdot 10^{10}$ at 7 kV $14 \cdot 10^{10}$ at 10 kV	
Wego 0·25 μF at 50 kV Coaxial	$50 \cdot 10^{10}$	Dr. R. F. Saxe, Qu Mary College, L don.
T.C.C. 0·06 μF at 5 kV Coaxial	$20 \cdot 10^{10}$	J. S. T. Looms, Natio Physical Laborato
58·5 μF at 25 kV Bank of smaller units used by Durnford and Reynolds	$24 \cdot 10^{10}$	J. D. Craggs and J. Meek, *High Volt Lab. Technique* (L don: Butterwo Scientific Pubii tions.)

It can be shown(17, 18) that, for applications where external circuit is of suitably low inductance, it is reasona to design a system around the special capacitors availab

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A design for a multi-channel infra-red spectrometer using transistor electronics

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[*Paper received* 26 *November*, 1957]

This paper describes a simple spectrometer in which a number of indium antimonide photoconductive cells are placed in the plane of the spectrum, each acting as its own "exit slit" and receiving light of different wavelengths. The output from each can be handled separately, or they can be coupled to record the difference in intensity at two wavelengths. A large number of ways of using these outputs are feasible and the instrument described was constructed to demonstrate the principles, rather than to solve any particular problem.

There exists an increasing demand for the use of infra-red spectrometers in industrial analysis and process control. Instruments for this purpose need not, as a rule, have very high spectral resolution, but in almost all cases some form of comparison between the transmissions of a sample and a standard absorption cell is required. For this purpose double-beam optical systems are used.(1) Such instruments should possess simple, rugged, optical systems, and be capable of operation under industrial plant conditions.

This paper describes a simple spectrometer in which a number of indium antimonide photoconductive cells(2) are placed in the plane of the spectrum, each acting as its own "exit slit" and receiving light of different wavelengths. The output from each can be handled separately, or they can be coupled to record the difference in intensity at two wavelengths. The measure of this difference can be made independent of source intensity changes or cell window fogging. A large number of ways of using these outputs are feasible, and the instrument described was constructed, for the 1957 Physical Society's Exhibition, to demonstrate the principles, rather than to solve any particular problem.

OPTICAL DESIGN AND PERFORMANCE

Most of the possible advantages of the design arise fr the properties of the indium antimonide cells. These h been described in an earlier paper,(2) but it is useful to rev the essential features for this application. They can c veniently be made in the form of thin strips of crys measuring say 5 × 0·5 mm, requiring no envelope being quite stable, in laboratory atmospheres at least. T a number can easily be arranged as a series of exit slits in spectral plane. Whilst their sensitivity over their useful ra from 1–7·8 μ, is perhaps ten times less than a Schw thermopile of comparable size, their very fast respo (less than 0·1 μs) means that the interruption frequency be chosen purely from the standpoint of simplifying subsequent circuitry.

The optical arrangement of the instrument and a schema diagram of the electronics is shown in Fig. 1. The sou used is a piece of Brightray heater tape, of area 10 × 0·5 r and about 0·012 mm thick. This was mounted in a hol which maintained a slight tension on the tape, sufficient retain its shape when heated to about 700° C. To shiel n draughts, the tape and its support were contained in a ll copper can with a periclase window, and it was iciently rigid to act as the entrance slit for the system. spectrometer had the conventional Littrow arrangement, loying a fluorite prism with a silvered back surface, and 5 cm diameter × 20 cm focal length spherical mirrors. mirrors and prism were enclosed in a Perspex housing, d with periclase windows for the radiation beams, which d as an absorption cell and for demonstration, could illed with appropriate quantities of methane.

he radiation was interrupted by a chopper, constructed a squirrel cage, and inverted over the source unit. A motor provided an interruption frequency of 1·7 kc/s. Mullard type OCP71 phototransistor was placed just in beam at the point shown in Fig. 1, and signals from this e used to give a reference phase for the phase-sensitive ifiers described below. Three indium antimonide cells e used in the apparatus, mounted on metal blocks in the ne of the spectrum at *AB* in Fig. 1. Their separation uld be varied by screw adjustments to set them to the sired wavelengths. The overall dimensions of the entire trument, including amplifiers but excluding output meters, re 35 × 20 × 25 cm.

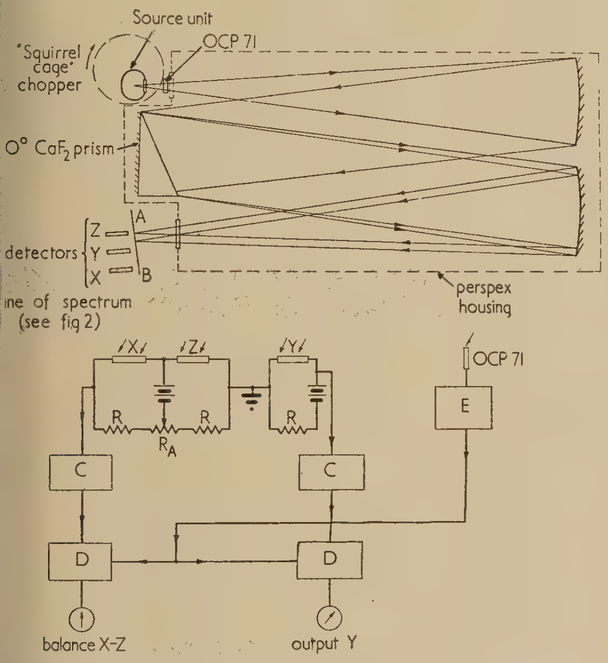

Fig. 1. Outline of optical and electronic arrangement
C, amplifier; *D*, drive unit and phase-sensitive rectifier; *E*, reference signal generator.

Of the many possible ways of using the outputs from the ree detectors, the one chosen to illustrate the principle volved the use of the detectors *X* and *Z* (Fig. 1) to monitor source temperature, whilst detector *Y* received radiation ound 3·4 μ and could be used to measure the quantity of thane in the Perspex housing. The operation of detectors and *Z* can be understood with reference to Fig. 2, in which intensity of radiation is plotted against distance along the e *AB* of Fig. 1 for three different source currents. A velength scale is included, and the positions and width of three detectors are shown. The three source currents respond very roughly to source temperatures of 780, 720 d 650° C (measured with an optical pyrometer) and an initial adjustment of R_A (Fig. 1) was made, with a source current of 821 mA, to give zero net output from the detectors *X* and *Z*. Changes in source temperature, up or down, then gave outputs from *X* and *Z*, the signs of which depend on whether the source current is increased or decreased, and which have values very sensitive to small changes in source temperature as shown in Fig. 3. Here the out-of-balance output is plotted as a function of source current changes about a mean of 821 mA. Noting that the gain of the amplifier is here forty times that used for the data of Fig. 2, it is seen that a 20 mA change in source current (2·5%) gives a change in output current of some 50–60 μA. (The asymmetry about the zero point is probably due to some stray light in the system giving rise to out-of-phase signals). Thus a change of 2·5% in source current, being a change of roughly 1·5% in source temperature, and of some 5% in output intensity in the 2·5–4·5 μ region, gives rise to an out-of-balance current which is sixty times the noise level in

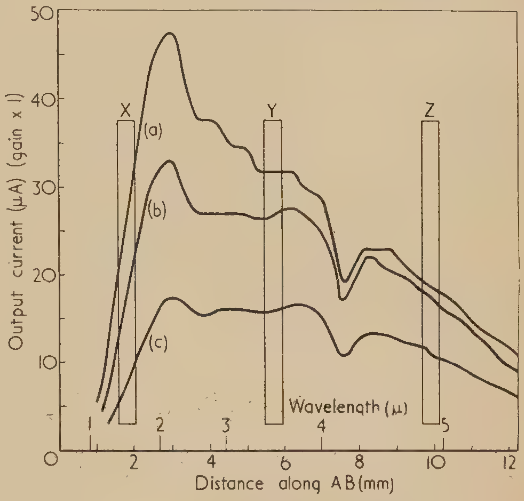

Fig. 2. Intensity distribution in the spectrum
Source current for curve (*a*), 900 mA; curve (*b*), 821 mA; curve (*c*), 720 mA.

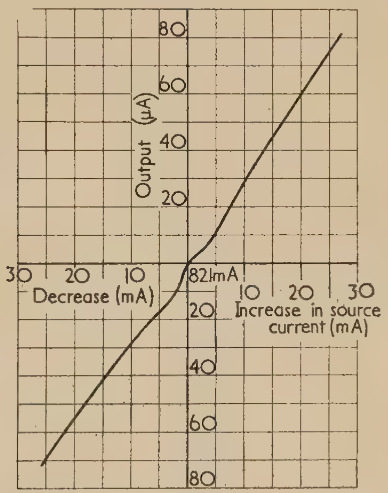

Fig. 3. Out-of-balance output with change in source current centred on 821 mA. The gain is forty times that used for Fig. 2

the system. It can be seen that this offers a very sensitive method of control of output intensity, and provided wavelengths X, Y and Z can be found for any particular problem which avoid interference between "wanted" absorptions at Y and clear regions at X and Z, the system offers the advantages of a double-beam system without its attendant optical complications.

An alternative mode of operation would employ, perhaps, detector X to monitor the source intensity by a direct measurement, the detectors Y and Z being set to compare the intensities of two different absorption bands. Obviously one is not limited to three detectors, and a great number of possible applications can be envisaged.

THE DESIGN OF THE ELECTRONICS

The use of transistors in the detector amplifier for an indium antimonide cell enables the design to be small in size and low in power consumption. For industrial applications, perhaps the main virtue of transistors is the absence of microphony. The indium antimonide cells can conveniently be made to have a resistance between 50 and 300 Ω. Since a transistor amplifier has an optimum noise factor with a source resistance of about 200 Ω, the cells are suitable for direct connexion. An input matching transformer is therefore not required; this is desirable when operating at low signal level as it could be a source of microphony. The indium antimonide cells have a fast response and enable the chopping frequency for the radiation to be chosen to avoid the poor noise factor of transistors below 1 kc/s.

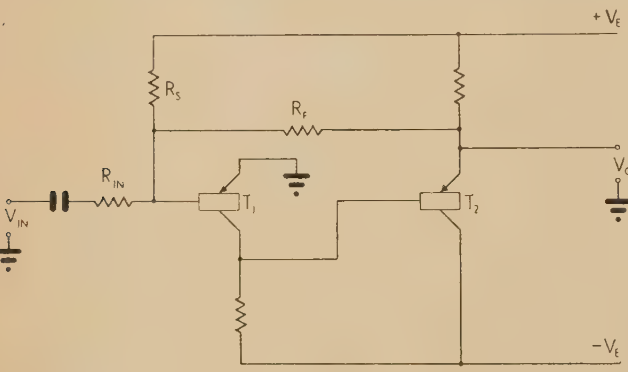

Fig. 4. The basic amplifier circuit

The above facts show that indium antimonide detectors fit in well with the requirements of a transistor amplifier f a noise point of view. A low noise transistor operated u these conditions can have a noise factor of between 2 ar (Noise factor is defined as the ratio of the apparent i noise power to the Johnson noise power in the so resistance.) The detector amplifier described is of the ho dyne type,(3) so as to obtain a narrow bandwidth and h enable small signals to be detected. The amplifier prece the phase-sensitive rectifier has a bandwidth which is adeq to accommodate any change in the speed of the m driving the chopping disk, and a narrow overall bandw is obtained by following the phase-sensitive rectifier wi low-pass filter.

The detailed design of the circuits shown in block for Fig. 1 will now be considered.

THE BASIC AMPLIFIER CIRCUIT

A basic amplifier circuit, which forms the basis of design of the complete amplifier, is shown in Fig. 4. amplifier consists of two transistors with negative feed applied in a similar way to a virtual earth amplifier o anode follower. Transistor T_1 is an earthed emitter s and it is directly coupled to transistor T_2 which is an em follower. Feedback is applied by resistors R_F and R_{in}. correct d.c. conditions are obtained by feeding a bias cu (R_s) into the virtual earth, which makes the output nega and ensures that the collector of T_1 is biased negative.

The application of feedback improves the freque response and makes the overall gain less dependent transistor parameters. Also, since it is d.c. feedback, quiescent operating conditions are made reasonably st with change in temperature. The change in output vo due to Ic_0 (collector-to-base peakage current) in T_1 is appr mately $Ic_0 \times R_F$. The overall gain (V_0/V_{in}) is given appr mately by the ratio of R_F to R_{in}, provided the overall g required is less than ten.

The circuit forms a useful basic "brick" in the design o amplifier because stages can be cascaded with little interact This is because the input impedance, which is approxima equal to R_{in}, is large in relation to the output impedance.

THE AMPLIFIER

The amplifier (Fig. 5) consists of three stages of the b circuit just described. It has a gain of 95 dB and a freque response which is 3 dB down at 300 c/s and 3 kc/s. bandwidth is determined in the second and third stages low frequencies by the input capacitors (C_1 and C_2) anc

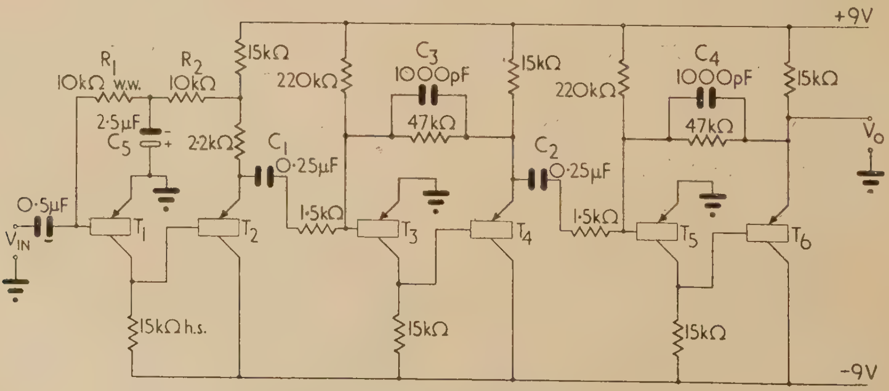

Fig. 5. The amplifier circuit

T_1 is chosen for low noise; T_2–T_6 are general purpose audio transistors.

frequencies by the capacitors (C_3 and C_4) in parallel the feedback resistors. Since the stages are similar, the of attenuation is 12 dB per octave.

order to obtain a low noise factor the first stage is erent from the second and third stages. An input resistor) must not be used or the noise factor of the stage will ncreased. Feedback could still be applied by using the stance of the cell as the input resistor, but as this may vary n one cell to another the voltage gain of the amplifier ıld also change. To avoid this the first stage has no feedk at signal frequencies. Feedback is applied to determine quiescent operating conditions and it is removed at signal uencies by a capacitor (C_5) from the junction of the lback resistors (R_1 and R_2) to earth. It is found that a er noise factor is obtained if the first transistor is operated small collector current, but little improvement results n a current of less than ½ mA.

THE PHASE-SENSITIVE RECTIFIER

simplified diagram of the phase-sensitive rectifier, which alf-wave, is shown in Fig. 6(*a*). The switch is operated he chopping frequency and feeds the signal current either arth or into the input of a virtual earth amplifier. This of phase-sensitive rectifier(4) has the advantage that, ause the signal is in the form of a current which flows er to earth or to a "virtual" earth, no large voltages are duced. Also, if the signal is fed from a true current rce, the voltage drift at the output of the amplifier is the e as that due to the input stage of the amplifier. The -pass filter (*CR*) which determines the overall bandwidth he system is included in the feedback path of the virtual h amplifier.

he switch for the signal current consists of two transistors . 6(*b*)] driven by the reference signal *via* a transformer. drive to the transistors is phased such that when one is ducting the other is off. Transistors form a very good ch and are a useful alternative to the usual use of diodes switching. A transformer is necessary to drive transistor in order to keep the reference signal separate from the ıt signal, and for symmetry transistor T_2 is also transmer driven, but this is not essential. The transistors are rated in an inverted state(5) (i.e. the roles of emitter and ector are interchanged) because this results in a lower age current when the transistor is switched off. A age current with germanium transistors of under 1 μA is lily obtainable at a temperature of 30° C. The effective r current fed to the virtual earth is less than this because the effects of leakage in the two transistors are in opposite directions.

The reference signal generator (Fig. 7) consists of a phototransistor (T_1) which is coupled by an emitter follower (T_2) to the squaring circuit (T_3 and T_4). The squaring circuit is a basic amplifier stage with diodes in the feedback arm to limit the output voltage to 2·5 V peak-to-peak.

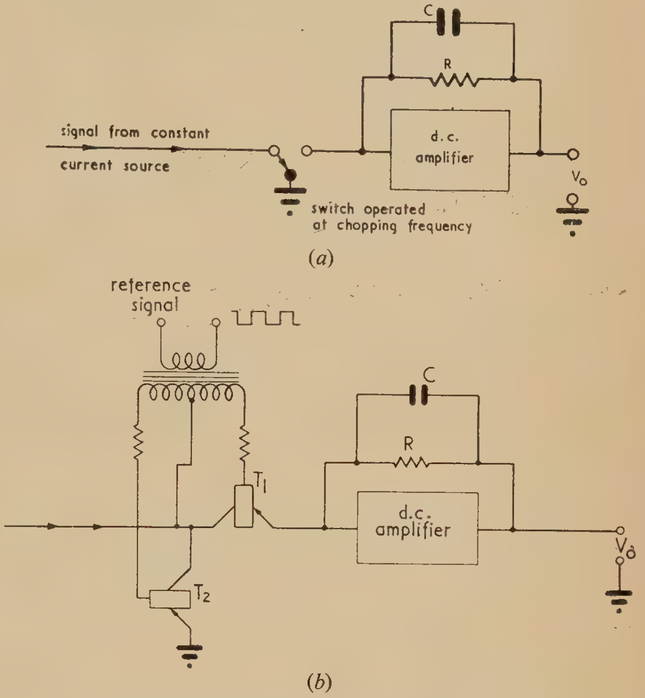

Fig. 6. (*a*) Block diagram of the phase-sensitive rectifier. (*b*) The phase-sensitive rectifier with transistors used for the switch

The high impedance drive circuit for the phase-sensitive rectifier (Fig. 8) consists of the basic amplifier circuit (Fig. 4) with the output taken from the collector of transistor T_2. A high impedance load is provided by transistor T_3. The circuit has a maximum gain of approximately 0·1 A/V.

The virtual earth amplifier (Fig. 8) following the rectifier is another basic amplifier circuit, with the first stage changed into a long-tailed pair to reduce drift with temperature. Provision is made to adjust both the virtual earth and the output to zero potential. Drift in the amplifier with a change

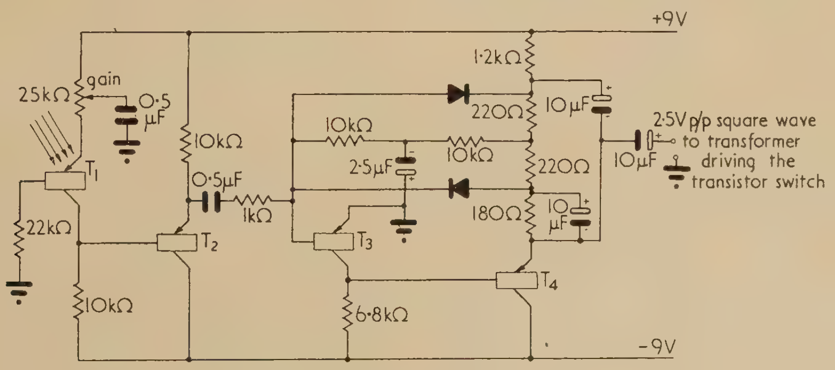

Fig. 7. Reference signal generator

T_1 is a phototransistor; T_2, T_3 and T_4 are general purpose audio transistors.

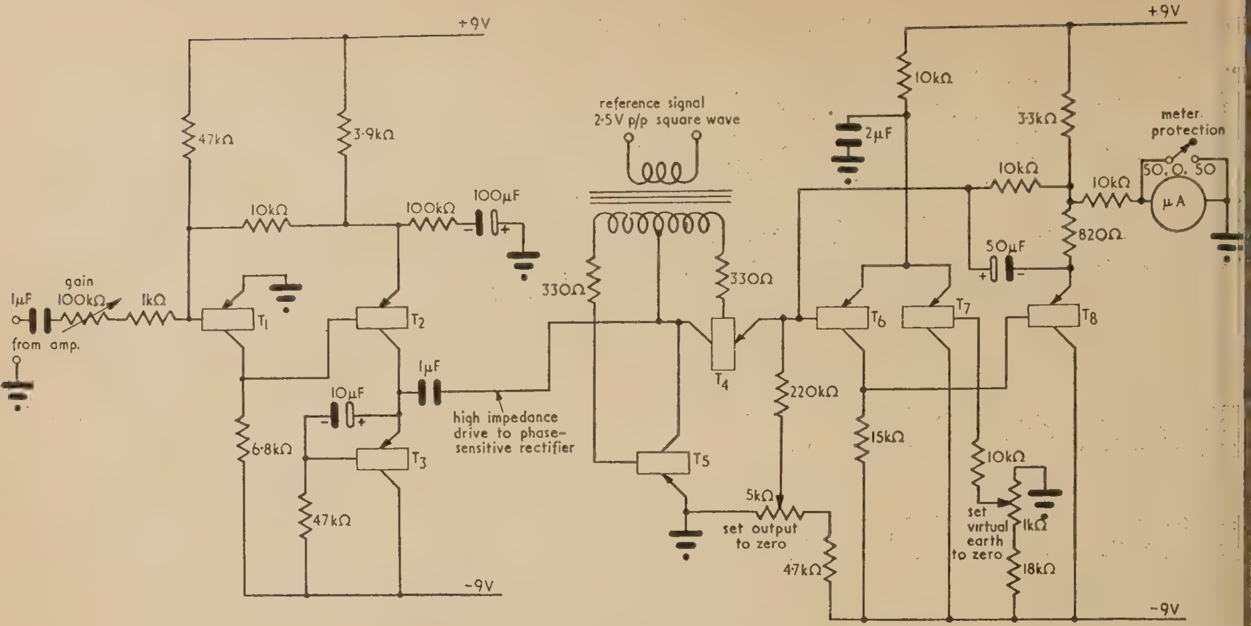

Fig. 8. High impedance drive circuit and phase-sensitive rectifier

All transistors are general purpose audio types; T_4, T_5 and T_6, T_7 should preferably be matched pairs.

in ambient temperature from 20 to 35° C is equivalent to an input signal to the phase-sensitive rectifier of less than 2 μA r.m.s. Overload of the amplifier takes place with an input signal of about 2 mA peak. These two figures limit the maximum ratio of noise-to-signal that the detector can handle. A reasonable minimum signal is 5 μA r.m.s. and 500 μA r.m.s. is the maximum noise input to avoid overload; therefore a noise-to-signal ratio of one hundred is possible.

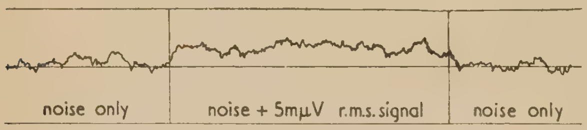

Fig. 9. Recording of output with 5 mμ V r.m.s. input

The circuit shown has a time constant (*CR*) of 0·5 s in the feedback path which gives an equivalent noise bandwidth of 1 c/s. With a source resistance of 300 Ω the Johnson noise generated is $\sqrt{(4\,k\,TBR)}$ V r.m.s. (T is the absolute temperature and B the bandwidth) which is equal to 2·3 mμ V. Fig. 9 shows a recording of the noise output and the effect of a 5 mμ V r.m.s. input signal. It can be seen that a signal-to-noise ratio greater than one is obtained.

CONCLUSION

The work was performed to demonstrate the possible uses of indium antimonide detectors and transistor electronics in this type of instrument. No attempt has been made to apply the instrument to any specific problem, but it is felt that a number of advantages could follow from such applications. Briefly these are:

(i) a multi-channel spectrometer can be made in which the outputs are independent of source intensity variation, cell-window fogging, etc., usually associated with double-beam instruments;

(ii) a simple rugged instrument along these lines could incorporate the well-known advantages of space saving and low power consumption associated the use of transistors. Such instruments use process control devices in chemical flow-lines w have the advantage that the fire risk from the circ would be greatly reduced;

(iii) the very fast response of the detectors, which m the use of low-noise transistor amplifiers poss would also mean that the instrument could be use a fast-response servo-system if desired, or for investigation of spectra from transient sources;

(iv) since the whole device can readily be operated f dry batteries, a portable version would present difficulty.

ACKNOWLEDGEMENTS

Thanks are due to Messrs. Henry Wiggin and Co., kindly supplied a quantity of Brightray heater tape for by the authors. The design and manufacture of the so unit was the work of Mr. W. H. Mitchell of R.R.E. authors would also like to record their appreciation of work of Mr. H. D. Holscher of R.R.E. on the electr circuits, and of the staff of F Block Workshops, R.R for constructing the demonstration equipment. Ackn ledgement is also made to the Controller of H.M. Statio Office, for permission to publish this paper.

REFERENCES

(1) WILLIAMS, V. Z. *Science*, **113**, p. 51 (1951). See *Rev. Sci. Instrum.*, **19**, p. 135 (1948).

(2) AVERY, D. G., GOODWIN, D. W., and RENNIE, A *J. Sci. Instrum.*, **34**, p. 394 (1957).

(3) SMITH, R. A., JONES, F. E., and CHASMAR, R. P. *Detection and Measurement of Infra-Red Radi* (London: Oxford University Press, 1957).

(4) NOBLE, S. W., and BAXANDALL, P. J. *Proc. Instn E Engrs*, **99** (2), p. 341 (1952).

(5) EBERS, J. J., and MOLL, J. L. *Proc. Inst. Radio E* **42**, p. 1765 (1954).

A sensitive micrometer for measuring small displacements

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A variable parallel plate capacitor associated with an oscillating circuit forms the basis of an apparatus which can measure small displacements of the order of 200 Å. The apparatus is so designed as to combine robustness with sensitivity, ease of calibration and reproducibility. The use of a diode pump integrator circuit makes the sensitivity independent of the gain of the a.c. amplifier. The capacitor is of simple construction and standard electronic components are used throughout.

accurate measurement of small displacements of the er of a few hundred ångström units often necessitates the of delicate equipment, which is unsuitable for many ential applications. An apparatus has been devised ch combines robustness with sensitivity and repro- ibility. The measuring device comprises a variable allel plate capacitor which forms part of an oscillating uit. The manner in which the displacement is measured kes it independent of the gain of the a.c. amplifier, thus bling the calibration to be easy and rapid.

THEORY OF THE METHOD

The oscillator circuit is shown schematically in Fig. 1. An n dust cored inductance L_1 is tuned by the parallel plate acitor C and the fixed input capacitance C_0. Approxi- tely, the frequency of oscillation is

$$f = 1/[2\pi\sqrt{L}\sqrt{(C + C_0)}] \qquad (1)$$

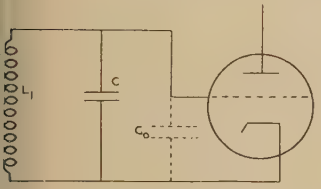


Fig. 1. Schematic diagram of oscillator circuit

A small change δC in C produces a change δf in f where

$$\delta f/f \simeq -\tfrac{1}{2}[\delta C/(C + C_0)] \qquad (2)$$

Ignoring edge effects the capacitance C of a parallel plate pacitor, having plate area A, dielectric of permittivity k d thickness x is

$$C = kA/4\pi x \qquad (3)$$

A small change δC in C is brought about by a change δx x where

$$\delta C/C = -\delta x/x \qquad (4)$$

us

$$\delta f \simeq \tfrac{1}{2} \,.\, C/(C + C_0) \,.\, f/x \,.\, \delta x \qquad (5)$$

When C is made very large compared with C_0, the term $(C + C_0)$ approaches 1 and δf becomes independent of It also follows that (*a*) δf is increased when f is made rge and x made small, and (*b*), since C is inversely pro- rtional to x, reducing x has the desirable effect of increasing and the sensitivity is enhanced.

The frequency of oscillation (f) of the tuned circuit is mpared with the fixed frequency of a crystal-controlled cillator, the difference in frequency being measured.

Unfortunately, tuned circuit oscillators are prone to equency drift, owing to extraneous causes (e.g. temperature anges, supply voltage variation, etc.), which becomes pro- unced at high frequencies. This imposes an upper limit the working frequency which must be chosen so that the ange in frequency δf is due only to changes in x. The frequency selected, namely 6 Mc/s, gives good stability whilst ensuring (*a*) adequate sensitivity, and (*b*) that the error due to frequency drift is "long term" compared with the time needed to determine a change in x.

DESCRIPTION OF APPARATUS

The parallel plate capacitor consists of two aluminium disks 8 in. in diameter and 0·060 in. thick, mounted on Tufnol blocks which carry steel inserts forming a sleeve bearing. These two steel inserts are accurately machined and slide freely, without side play, into each other. No lubricant is used between them. The plates are mounted horizontally

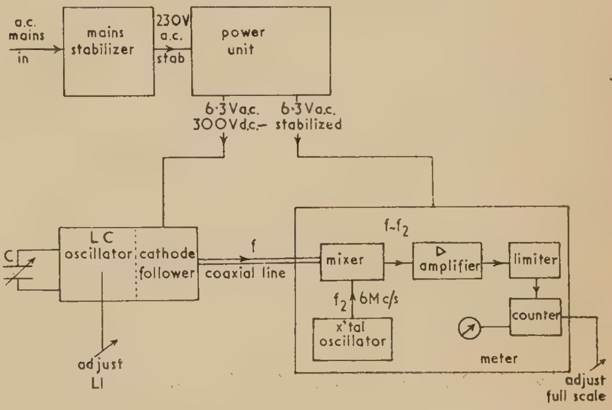
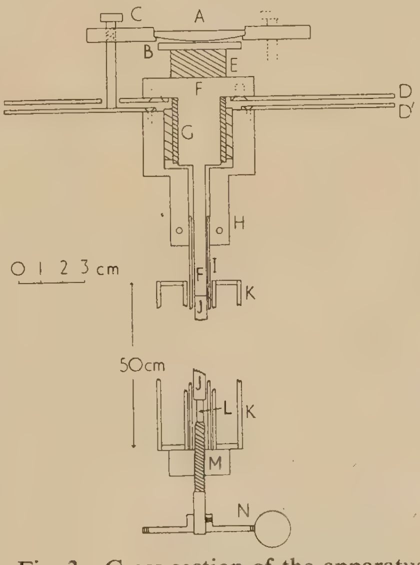


Fig. 2. Block diagram of apparatus for measuring small displacements



A, weak convex lens; *B*, glass flat mounted in *C*; *C*, tripod support with adjustable legs; *DD′*, $\frac{1}{16}$ in. Dural plates; *E*, steel weight, 340 g; *F*, Tufnol plug and push rod; *G*, ground steel bearing inserts; *H*, Tufnol member attached to *I*; *I*, specimen tube; *J*, rod specimen fitting in tube *I*; *K*, double-walled copper jacket; *L*, fine pitch (40 turns per in.) screw, fitting into *M*; *M*, nut soldered to *K*; *N*, worm gear for zero adjustment.

Fig. 3. Cross-section of the apparatus for a rod specimen

and the upper plate is secured to a low expansion push rod, made from Tufnol (linear coefficient of expansion approximately $3 \times 10^{-6}/^\circ$ C), the other end of which is maintained in contact with the member undergoing displacement. The plate assembly is supported in some convenient manner depending on the use being made of the instrument.

The plates are connected to the oscillator unit by flexible leads which do not restrain the movement of the upper plate. The output from the oscillator is taken *via* a cathode follower valve and coaxial line to the measuring unit. The general arrangement is shown in Fig. 2.

In one form of the apparatus a specimen in the form of a rod is placed below and in contact with the push rod. The zero setting adjustment is made by a fine pitch screw in contact with the lower face of the specimen (Fig. 3).

STANDARDIZATION OF APPARATUS

Initially, f, C and x [see equation (5)] are set to some convenient fixed values. The value of the capacitance C, considerably greater than C_0, is selected according to the range of displacement. A standard capacitor set to this value is connected in the oscillator circuit, replacing C, and the frequency of the oscillator varied by adjusting the iron dust cored inductance L_1 until it is at zero beat with the crystal oscillator (the precise manner in which this is accomplished is given later). This adjustment is very sensitive, enabling the frequency to be set to within a few kilocycles of 6 Mc/s. The standard capacitor is then removed, the parallel plate capacitor connected in its place and the spacing of the plates adjusted by the zero setting device, to give zero beat. Capacitor C then has the same capacitance as the standard capacitor and the oscillator frequency is set at 6 Mc/s. Since C is proportional to $1/x$ it follows that x has also been set to a fixed value.

The change in frequency is measured in a diode pump integrator circuit.$^{(1)}$ In this arrangement, essentially square-topped pulses of constant amplitude are passed to an integrating circuit and the rectified current is recorded on a microammeter. It has been established$^{(1)}$ that, for the arrangement shown in Fig. 4, when square-topped pulses of constant amplitude E, pulse repetition rate n, are applied, the steady voltage v appearing across R_1 is

$$v = nR_1C_1E$$

provided $E \gg v$ and $R_1C_2 \gg 1/n$.

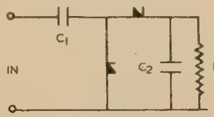


Fig. 4. Integrator circuit

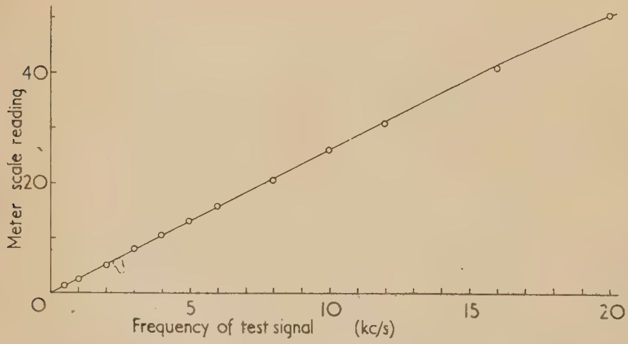


Fig. 5. Linearity of frequency-measuring unit. Plot of meter reading *versus* frequency

The integrator circuit has been modified to enable a bri type instrument rectifier to be used. The linear relation between the meter reading and the change in frequency been experimentally verified (Fig. 5).

By altering the time constant of the integrating circuit full-scale deflexion of the microammeter can be adjuste cover a wide range of frequency (i.e. from 50 c/s to 20 in the present apparatus). The full-scale deflexion of meter is standardized by feeding a signal of known frequ into the grid of V_4 (Fig. 6), at a level sufficient to cause to limit, and adjusting the variable resistance *RM* until meter reads full scale.

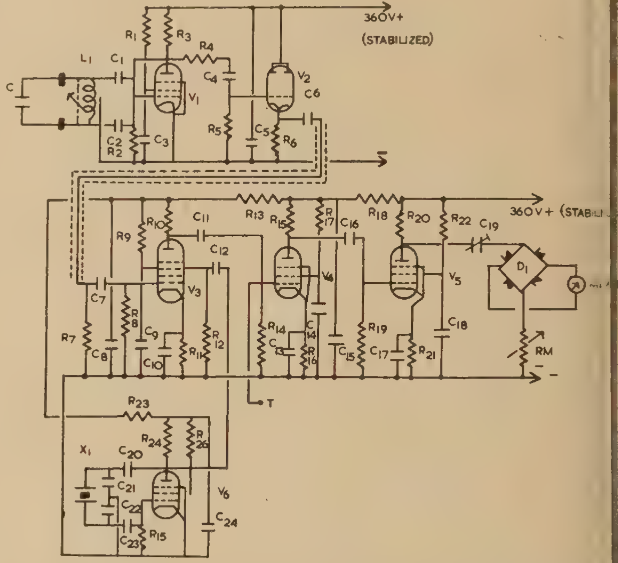


Fig. 6. Circuit diagram of measuring apparatus

$R_1 = 22$ kΩ
R_2 100 kΩ
R_3, $R_4 = 10$ kΩ
$R_5 = 100$ kΩ
$R_6 = 270$ Ω
$R_7 = 75$ Ω
$R_8 = 56$ kΩ
$R_9 = 27$ kΩ
$R_{10} = 15$ kΩ
$R_{11} = 470$ Ω
$R_{12} = 56$ kΩ
$R_{13} = 1$ kΩ
$R_{14} = 56$ kΩ
$R_{15} = 10$ kΩ
$R_{16} = 180$ Ω
$R_{17} = 22$ kΩ
$R_{18} = 1$ kΩ
$R_{19} = 100$ kΩ
$R_{20} = 56$ kΩ
$R_{21} = 270$ Ω

$R_{22} = 10$ kΩ
$R_{23} = 22$ kΩ
$R_{24} = 47$ kΩ
$R_{25} = 100$ kΩ
$R_{26} = 56$ kΩ

$C_1 = 0{\cdot}001$ μF
$C_2 = 47$ pF
$C_3 = 0{\cdot}1$ μF
$C_4 = 0{\cdot}01$ μF
$C_5 = 0{\cdot}1$ μF
$C_6 = 0{\cdot}01$ μF
$C_7 = 0{\cdot}05$ μF
$C_8 = 0{\cdot}1$ μF
$C_9 = 0{\cdot}05$ μF
$C_{10} = 50$ μF
$C_{11} = 0{\cdot}1$ μF
$C_{12} = 10$ pF
$C_{13} = 50$ μF
C_{14}, $C_{15} = 8$ μF

$C_{16} = 0{\cdot}1$ μF
$C_{17} = 50$ μF
$C_{18} = 8$ μF
C_{19} = Pye trimmer 2–20 pF
$C_{20} = 0{\cdot}01$ μF
C_{21}, $C_{22} = 47$ pF
$C_{23} = 33$ pF
$C_{24} = 0{\cdot}01$ μF

V_1 = 6AM6
V_2 = 12AT7 strapped in parallel
V_3 = 6L7
V_4, V_5, V_6 = 6AM6

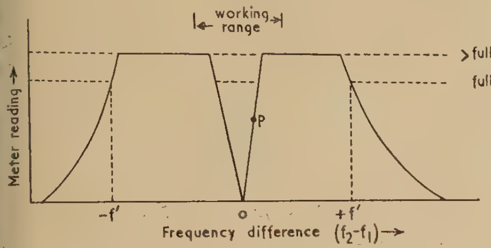
L_1 = variable, approximately 4 μ
X_1 = crystal 6000 kc/s, R.C.A. FT243

D_1 = bridge type instrument rect
M_1 = 0–50 μA M/C

OPERATION OF THE MEASURING UNIT

In the measuring unit, the incoming signal at frequency is mixed with the output from the crystal oscillator, at frequency f_2 to give a beat frequency $(f_1 - f_2)$, far remov from f_1 and f_2. This difference frequency component amplified and limited to give approximately square-wa pulses of constant amplitude. The action of the limiter va makes its output largely independent of (*a*) the amplitu of the input signals, provided they exceed a certain lev and (*b*) variations in the gain of the amplifier. The mi valve V_3 provides a useful output at frequencies (f_1 – down to less than 50 c/s and up to frequencies of 20 kc but the response of the untuned amplifier is restricted. The amplifier gain, however, enables the limiter to opera from approximately 10 c/s to above 20 kc/s. When f_1 = the meter will read zero, but frequency shift in either directi this point will produce a deflexion. The variation in r deflexion with ($f_1 - f_2$) is shown in Fig. 7.

he working range is easily found; it is characterized by op in the meter reading to zero for the position where f_2. A convenient initial setting, shown as point *P* in 7, is the mid-scale position of the indicating meter



g. 7. Variation in microammeter reading with change measured frequency. The characteristic dip through zero is shown in the middle of the working range

ved at after passing through zero, when screwing the ometer screw *upwards* (reducing *x*). Increases in *x* are shown as positive deflexions. The correctness of this ng can be established by bringing an earthed object the hand) towards the edge of the plates, thereby easing the capacity, which should cause the meter exion to decrease to zero, and then increase again.

CALIBRATION OF THE APPARATUS FOR ROD SPECIMENS

he meter scale reading is calibrated in terms of absolute lacement by a conventional optical interference method. arrangement with a rod specimen is shown in Fig. 3. tiple reflexions of sodium vapour light between a glass and a weak lens produce sharp Newton's rings. The acitor plate can be moved by causing the specimen to and very slowly so that a progressive movement of the ge system results, e.g. by carefully controlled electrical ing of the specimen, The fringe pattern is observed in icroscope, and the microammeter reading noted as each ge moves past the cross-wires. About forty fringes can counted for a full-scale deflexion setting of the meter at c/s.

source of error which needs to be considered is that of imation. The centre of the fringe system must be viewed the axis of the microscope perpendicular to the glass ; the distance measured is then the motion normal to this ace. The glass flat should be perpendicular to the axis he specimen in the direction of expansion. The error is portional to $(1 - \cos\theta)$, θ being the angle between the of the microscope and the normal to the flat. By careful hanical design this error can be reduced to a negligible ount.

he interference fringes are made very sharp by half-ering the lens and flat, but calibration with moving fringes olves errors in reading the meter, probably to half of one er scale division, i.e. 1% of full-scale deflexion.

STABILITY OF THE APPARATUS

he stability of the oscillator is an important consideration. minimize oscillator drift, the a.c. mains supply was ilized using a General Radio type B.A.T. transformer the h.t. supply to the oscillators and measuring unit was ained from a stabilized power unit.

he oscillator drift was investigated and it was found that after the equipment had reached thermal equilibrium (three hours) this drift was long term, having a maximum of 1·6 kc/s per hour. Under these conditions the time taken for one reading can be several minutes with negligible error.

The apparatus was stable under normal laboratory conditions where ambient temperature changes were small. The design and location of the framework supporting the apparatus ensured that minimum mechanical vibration was transmitted from the surroundings.

SENSITIVITY

Fig. 8 is a calibration graph for a sensitivity setting of 20 kc/s full-scale deflexion (i.e. $12 \cdot 5 \times 10^{-4}$ cm displacement). Although the relationship is not linear over the whole

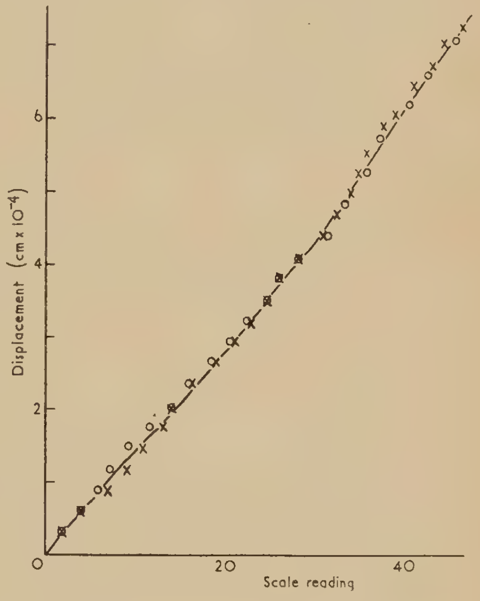


Fig. 8. Standardizing curves

○ = first calibration; × = second calibration after re-standardizing at 250 pF, 20 kc/s, full-scale deflexion.

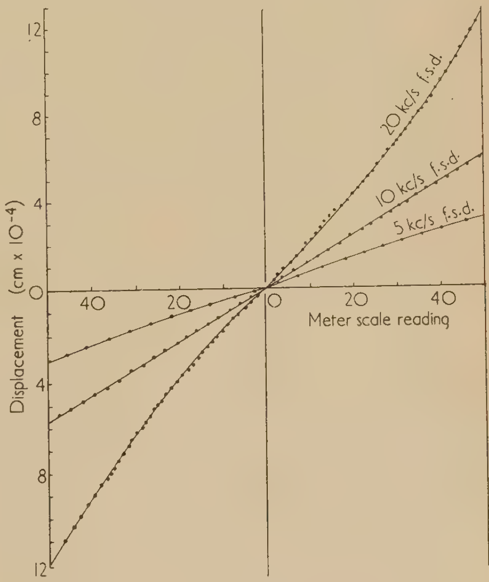


Fig. 9. Calibration curves

meter scale reading, there is no difficulty in determining the displacement. The most sensitive part of the curve is near the origin where the sensitivity is approximately 2×10^{-5} cm per scale division on the microammeter. It is easily possible to read this scale to half a division. Two sets of calibration points are shown, the second being obtained after deliberate alteration of the adjustments, and re-calibration. They therefore indicate the reproducibility of the apparatus.

Fig. 9 shows calibration graphs for settings of 20, 10 and 5 kc/s. The corresponding maximum displacements are $12 \cdot 5 \times 10^{-4}$, $6 \cdot 25 \times 10^{-4}$ and $3 \cdot 1 \times 10^{-4}$ cm. The displacement per division for the most sensitive setting is $6 \cdot 2 \times 10^{-6}$ cm per scale division. The reading can be estimated to a quarter of one division, equivalent to a displacement of 200 Å approximately. For a rod speci
50 cm long, strains of the order 4×10^{-8} to 25 ×
could be detected.

ACKNOWLEDGEMENTS

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are also due to Mr. R. A. Hacking, Director of Resea
for permission to publish this paper.

REFERENCES

(1) Earnshaw, J. B. *Electronic Engng*, **28**, p. 26 (1956
(2) Terman, F. E. *Radio Engineering*, p. 235 (New Y
McGraw-Hill Book Co. Inc., 1947).

Leak testing of vacuum plant by helium analysis

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An apparatus is described for determining the extent and location of leakages in the operation of gas plants, working at reduced pressures, by the analysis of the rare gases, helium and neon, contained naturally in the inleaking air. It can generally be applied when hydrogen, helium and neon are normally absent from the plant gases. An accuracy of 0·5% for the analysis of a sample of gas containing 0·5 ml. of leakage air can be obtained, but it appears that the detection of 0·01 ml. of air is the lower limit using a commercial ionization gauge as the sensitive element.

When operating plants under reduced pressure it is necessary to have means of checking on the leak rate at various positions in the plant under operating conditions. Methods have been developed using continuous flow recording mass spectrometers, but these instruments involve a high initial financial outlay and are sometimes subject to lack of stability after operation over prolonged periods. A method has been developed using an apparatus which is simple and robust in design, not unduly expensive to build and relatively easy to operate. It involves the removal of a sample of gas from the plant and the chromatographic separation from the sample of the bulk of lighter gases, helium and neon, contained in the gas owing to inleakage of air. The principle is similar to a gas separation demonstrated by Dewar,⁽¹⁾ in which neon and helium can be partially separated from most other gases by passing the latter through a cooled charcoal tube, but it differs in so far as, under the conditions used here, a quantitative measurement is achieved. The helium and neon contents of air are 5·24 and 18·1 parts per million by volume respectively.⁽²⁾ If necessary, the gas sample can be returned to the plant after analysis.

OUTLINE OF METHOD

A sample of plant gas, of constant volume and pressure, is slowly adsorbed on a cooled charcoal column, by which process a chromatographic separation of any light gas fraction is obtained. This fraction of weakly adsorbed gas is washed continuously towards the front of the column by the more strongly adsorbed plant gas. When the pressure in front of the column attains a given value, no more gas is allowed to flow in, but the lighter fraction is washed further into a second smaller cooled column in which complete separation from the accompanying plant gas is achieved. The pressure of the light fraction, helium plus neon, is measured by an ionization gauge previously calibrated against standard gas samples.

APPARATUS

The method was designed for the analysis of samples w
drawn from sections of a gas plant and the initial deve
ment was carried out using samples of oxygen, nitroge
argon to which had been added varying small amount
air. Consequently, the dimensions and quantities of
apparatus described here apply to the examination of sam
consisting mainly of gases of this type. With gase
different adsorptive properties the apparatus will nee
be modified slightly by using different quantities of
charcoal in the columns. The apparatus is shown diagr
matrically in Fig. 1.

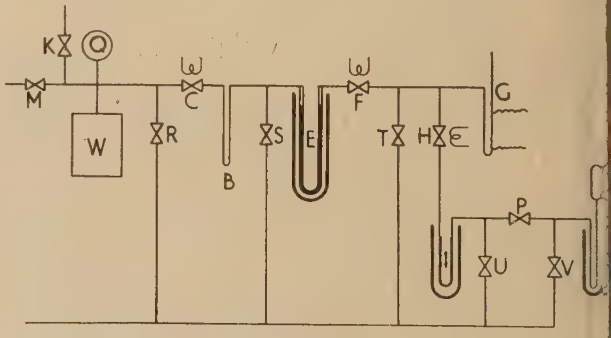

Fig. 1. Apparatus for the helium analysis of gas sample

Gas reservoir. Sample gas is fed into the reservoir
through valve M. Pressure gauge Q allows the pressure
be measured to an accuracy of ±0·1% and to be adju
to a constant value by the addition, if necessary, of
plant gas through valve K. The reservoir section betw
valve M, K, R and C need not be accurately calibrated si
the method is standardized by using samples of kno
composition, i.e. containing small measured volumes of
Capillary B, 36 cm long and 0·05 cm internal diame

luces standard flow conditions of gas from the reservoir the charcoal column *E*.

lain adsorption column. The adsorption column at *E*, ked with 4·5 g of graded 40/60 standard mesh gas coal, forms a column 34 cm long and 0·5 cm diameter; surrounded by a container suitable for holding liquid ogen. For these experiments, with the reservoir *W* having lume of 1·3 l., this was found to be the optimum quantity charcoal. For other gases the weight of charcoal in *E* st be related to the volume of *W* such that when the led charcoal in *E* is completely saturated, there is sufficient ssure remaining in the reservoir *W* to maintain an adequate and to build up the required pressure in the manometer allow electrical contact to be made.

is necessary that a reasonably fast gas flow rate through charcoal column *E* should be maintained (upwards of n linear flow per second) in order to avoid any back usion and longitudinal remixing of the separated light gas tion. In the method applied to the analysis of nitrogen nples, a convenient time interval between the beginning of flow from the reservoir and the build-up of the required ssure in manometer *G* was found to be 6 ± 1 min, during ich time approximately 1 l. of gas was taken up by the rcoal. The manometer *G* is fitted with electrical contacts that a pressure of approximately 9·0 cm of mercury ses a circuit and operates relays I and II and electrognetic valves *C*, *F* and *H* in a given sequence (see . 2).

Second adsorption column. The gas passing through *H* ers the adsorption column *I* which contains 0·5 g of rcoal, graded 40/60 mesh, in a column 3·5 cm long and 5 cm diameter; this column is also surrounded by a vessel contain liquid nitrogen coolant.

Ionization gauge and "getter." The light gas fraction ich reaches the ionization gauge *L* enters by passing ough a further small charcoal column in the U-tube *O*, ain cooled with liquid nitrogen, which acts as a "getter." contains 0·1 g of 40/60 mesh graded gas charcoal in a umn 1·5 cm long and 0·35 cm diameter.

The ionization gauge *L* [type IG-2H by W. Edwards and . (London) Ltd.] is operated from a power unit type 1075D Atkins, Robertson and Whiteford Ltd., Glasgow). This wer unit is calibrated with respect to dry nitrogen for use th the above ionization gauge and can be switched to four ssure ranges, these being 0–4 × 10^{-3}, 0–4 × 10^{-4}, 4 × 10^{-5} and 0–4 × 10^{-6} mm of mercury pressure. In , it is found most convenient to work on the range 4 × 10^{-5} mm of mercury pressure where an indicated ssure change of 0·8 × 10^{-5} mm of mercury is obtained the analysis of a sample containing 0·5 ml. of air.

Greater sensitivity of measurement results with the use of galvanometer to measure the ion current, means being ovided on the power unit to plug in an external galvanometer. Therefore, a d'Arsonval mirror galvanometer (type No. 41148/2 by the Cambridge Instrument Co. Ltd.) is used. This galvanometer has a 450 Ω coil resistance and gives a deflexion of 1100 mm at 1 m/μA. It is suitably shunted and damped so that for the analysis of a gas sample containing 0·5 ml. of air, a deflexion of 370 mm is obtained, this deflexion corresponding to a pressure change of 0·8 × 10^{-5} mm of mercury as indicated by the power unit meter, set on the appropriate range.

If desirable, a continuous recording of the ion current can be obtained by the use of a suitable mechanical recorder.

Electromagnetic valves. Electromagnetic oil dilution valves (type FAW/A/221, by Teddington Controls Ltd.) of normal operating voltage 24 V d.c. are used at *C*, *F* and *H*. The hard plastic plunger seatings were replaced by soft natural rubber disks and care was taken during reassembly to ensure that the valves were vacuum tight. A thin surface coating of high vacuum grease was applied to the rubber washer which fits between the two sections of the valve. In practice it is found that the valves heat up when operating at 24 V but, in general, they operate at 12–15 V without warming-up appreciably.

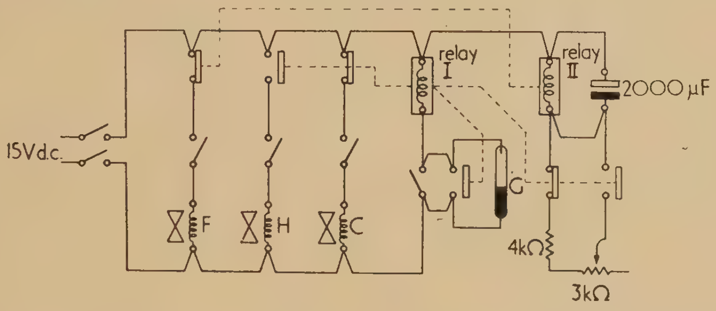

Fig. 2.
Control circuit

Between *C* and *F*, and *H* and *L*, it is essential to keep the dead space to a minimum without unduly restricting the gas flow, and tubing of 0·5 cm internal diameter has been found of suitable dimensions.

Electrical control circuit. Fig. 2 shows the electrical circuit used to control the electromagnetic valves. Initially relay I is open and relay II closed, in which positions valves *F* and *C* are open and valve *H* shut. On the circuit being closed by the manometer *G*, relay I is closed, valve *C* is shut and valve *H* opened. Relay II has its direct voltage supply cut on the closing of relay I but it remains closed whilst the 2000 μF capacitor discharges, then on opening it closes the valve *F*. By means of the variable 3 kΩ resistor it is possible to vary the period of time that relay II remains closed after its direct voltage supply has been cut. In practice, a delay time of ten seconds was found adequate. To facilitate pumping-out the apparatus, each electromagnetic valve has a manually-operated single-pole switch in its circuit (these are not shown in diagram). It is also convenient to have a single-pole switch to short out the mercury manometer switch.

PROCEDURE FOR SAMPLE ANALYSIS

Initially the whole apparatus is evacuated, using the connexions through valves *R*, *S*, *T* and *U* to a high vacuum pumping system and the charcoal columns are activated by baking out at a temperature of 300° C. In order to maintain constant test conditions, the baking-out procedure for activating the charcoal in columns *E* and *I* should be standardized. It was found sufficient to heat them to 300° C for five minutes with a small surrounding oven whilst evacuating. The ionization gauge is out-gassed following the procedure laid down by the manufacturers, and subsequently the "getter" and U-trap *O* are cooled with liquid nitrogen. With the ionization gauge operating normally, and the ion current having reached a steady low value, the apparatus is ready for sample analysis.

Continuous half-minute galvanometer readings are taken as the analysis proceeds in the following way. All the valves are shut and the relays set so that relay I is open and relay II closed, the electromagnetic valves being shut with the manually operated switches. Both adsorption columns *E* and *I* are immersed in liquid nitrogen, and, after five minutes, valve *P* is opened. To obtain repeatable results, it is essential to keep conditions constant and the liquid nitrogen in the baths surrounding *E*, *I* and *O* must be kept topped up to a fixed level. The gas sample is fed into the reservoir and the pressure is brought up to atmospheric pressure or some other standardized pressure; if necessary, pure nitrogen or oxygen is added.

The electromagnetic valves *C*, *F* and *H* are switched on manually and the gas is slowly adsorbed by the charcoal in column *E*. Five to seven minutes after commencing the adsorption of the gas, the pressure in manometer *G* should be sufficient to close the circuit and operate the relay system, whereupon valve *C* shuts and *H* opens. During the ten seconds delay before relay II opens and valve *F* shuts, adsorbable gas at low pressure washes the lighter gases through into column *I*, and an immediate increase in ion current is observed as these gases pass further into the ionization gauge. When the ion current has settled at a new constant value, it is advisable to shut valve *P*. The final reading of gauge *Q* is noted. From a preliminary calibration of gauge *L* against standard gas samples, the calculation of the air content of the gas sample is now made.

To prepare for the next analysis, before evacuating the rest of the apparatus, the ionization gauge should be pumped out until a low steady value of ion current is obtained, as is indicated by a constant galvanometer reading, and the gauge then closed off from the rest of the apparatus by valves *P* and *V*. If the liquid nitrogen in U-trap *O* is kept topped up and does not evaporate completely overnight, the gauge should operate satisfactorily for several days without needing de-gassing or the charcoal "getter" reactivating. Care must be taken to avoid any air getting into the gauge since it will then be necessary to repeat the degassing procedure and to reactivate the charcoal.

The remainder of the apparatus is then evacuated and the charcoal columns are baked at 300° C for five minutes.

RESULTS

Fig. 3 shows typical plots of galvanometer deflexion with time for the analysis of three gas samples containing approximately 0·5 ml. of air. Where the ion current shows initially a slow rise or fall, an extrapolation has been made to obtain a "corrected" total deflexion. The "corrected" deflexions are converted from scale readings to angular deflexions of the galvanometer. The results of these three runs are tabulated below and the standard deviation of the meth
found to be ±0·36% (see Table).

Using gas samples containing varying amounts of a
plot was obtained for ion current against millilitres o
added. As is shown in Fig. 4, the plot is not linear. O

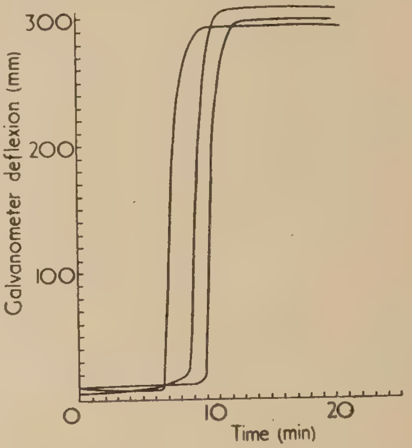

Fig. 3. Plots obtained for the analysis of three samp
containing about 0·5 ml. of air

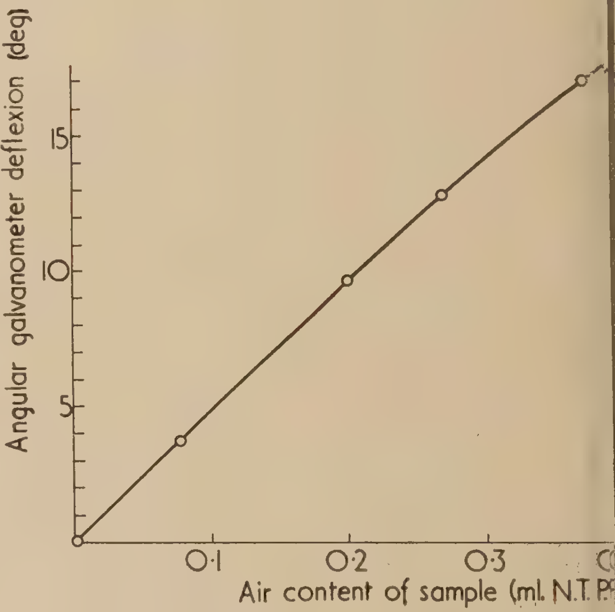

Fig. 4. Variation of ion current with air content
standard samples

to the fact that the ion gauge was not thermostatic
controlled, the lower limit of detection of air by the met
was determined by the variation of the gauge reading du
drifting with temperature change, etc., this limit being of
order of 0·01 ml. of air in the gas sample being analy

Typical results for the analysis of gas samples

Air taken (ml. N.T.P.)	*Gauge Q Initial press*	*Gauge Q Final press*	*Air in gas used (ml. N.T.P.)*	*Corrected angular deflexion (deg.)*	*Angular deflexion per ml. air N.T.P. (deg.)*	*Deviation from mean (%)*
0·4631	70·8	13·7	0·3737	16·42	43·95	+0·15 = +0·34
0·4628	71·0	14·75	0·3667	15·98	43·58	−0·22 = −0·50
0·4622	71·6	15·4	0·3627	15·91	43·87	+0·07 = +0·16
					Mean 43·80	
						Standard deviation 0·36

ough this is an adequate sensitivity for the practical ication of the method, refinements of technique giving oved gauge stability would considerably lower the unt of air which could be detected.

ne method is applicable to a large variety of purposes lving the analysis of the light gases helium, neon and ogen. Apart from the leakage control of vacuum plant, s been applied successfully to the analysis of samples of ery gas for helium content. These gas samples consisted mainly of methane and results were obtained in the range of 1–200 parts per million.(3)

REFERENCES

(1) Dewar, J. *Proc. Roy. Soc. London*, **74**, p. 127 (1904).
(2) Glueckauf, E. *Proc. Roy. Soc. A*, **185**, p. 89 (1946).
(3) Glueckauf, E., and Kitt, G. P. *Helium in methane gas from collieries*, A.E.R.E. Report C/M 240 (1955).

Laboratory and workshop notes

Calibrating manometer for pressure transducers

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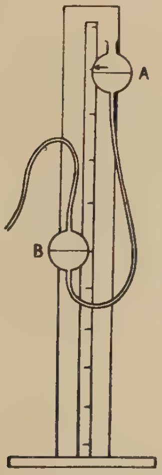
lote first received 16 *October*, 1957, *and in final form* 16 *January*, 1958]

alibrating pressure transducers it is convenient to produce 1own pressure directly rather than to raise the pressure or example, a small flask, and then to measure this with ater or mercury manometer. The latter practice—apart 1 being slower—complicates sensitivity calculations as it ifficult to produce or reproduce exact pressures.

1 this field the device to be described has proved very venient. It consists of two glass reservoirs *A* and *B*, fixed, one movable, connected with a rubber tube, and h half full of some suitable liquid (mercury, stained water, or alcohol). The movable reservoir *A* may be held by a ng clip if water filled, or a clamp if mercury filled, and fixed reservoir *B* is positioned so that, when the levels the two are equal, they are opposite an arbitrary zero k (which may conveniently be 50 cm on a meter stick). ow the tube from the top of the fixed reservoir is connected a transducer head of reasonably low admittance and the er reservoir is raised or lowered, then a corresponding itive or negative hydrostatic pressure will be applied to transducer.



Diagrammatic sketch of calibrating device for pressure transducers

the pressures are small, and the area of the transducer hragm small compared with the surface area of the id in the reservoir, pressures may be read directly, once zero has been set. If, on the other hand, significant air vement occurs, due either to a large diaphragm displace-t in the transducer or to air compression when using a cury column, the pressure will always be somewhat lower than the set value. The movement of the reference level can, however, easily be corrected for by a further raising or lowering of the movable reservoir, since any change in the "fixed" level is immediately visible. By thus raising or lowering the movable reservoir, the output of a transducer corresponding to any positive or negative pressure in the range ±50 cm (of water or mercury) may be rapidly determined, or alternatively the pressure required to give a predetermined output may be measured. This ability to reproduce exact pressures permits a transducer to be checked very rapidly, both for sensitivity and for linearity.

For reasons already referred to, the air tube from the fixed reservoir should be of as small bore as practicable, but that connecting the two reservoirs should be large enough to ensure an unimpeded flow of liquid, even at low pressure differences. Provided that both reservoirs are slightly less than half full then, even if one drains completely into the other, it will not overflow, the levels returning on resetting to the zero position.

This unit was designed in the course of a research programme on neonatal respiratory disease supported by a grant from the Scottish Hospital Endowments Research Trust.

The preparation of pure sulphur for physical measurements

By R. J. Berry, B.Sc., Division of Applied Physics,
National Research Council, Ottawa, Ontario

[*Note first received* 15 *November*, 1957, *and in final form* 9 *January*, 1958]

In connexion with the study of the reproducibility of the sulphur boiling point as a fixed point for the International Temperature Scale, we have been obliged to consider in some detail the effects of impurities, particularly dissolved gases, on the properties of sulphur.

Elemental sulphur is available with high chemical purity (99·98% or better) and a successful method of removing small amounts of residual organic impurity has been described.(1) At the same time, much attention has been given by earlier workers(2–5) to the effects of gaseous impurities, but no satisfactory technique for their removal has been developed. Bacon and Fanelli(1) tried alternate freezing, pumping, and melting using a pressure of 1 mm of mercury and found twelve such cycles were necessary to remove dissolved gases. Malus(6) on the other hand reported fresh gas evolved after eighty successive fusions under a pressure of 2–3 cm of mercury.

We have tried the above method but with a pressure of 10^{-3} mm of mercury and find that there is no visible trace of dissolved gas after a single cycle. If after degassing, the sulphur is allowed to solidify in contact with air an appreciable amount of gas is again evolved when the sulphur is melted.

About 250 g of pure sulphur were allowed to solidify in a 500 ml. Pyrex flask open to the air. The flask was then evacuated to a pressure of 10^{-3} mm of mercury or less with a liquid air trap in the line. As the sulphur melted, the gas evolved was pumped off for a period of an hour with the temperature of the sulphur not exceeding 150° C.

Using the same apparatus, we have estimated the solubility of air, nitrogen, and helium in sulphur at its melting point. After a preliminary degassing of the sulphur, it was exposed to one atmosphere pressure of the gas being considered for about two hours before freezing (the minimum time for saturation was about one hour; see table). The system was then put under static vacuum and the pressure of the gas evolved on remelting was measured with an oil manometer. The absolute error in the results presented in the table may be as high as 50%, but the relative error should be very much less. Justification for using the freezing temperature and the assumption that all the gas remained in the sulphur on freezing may be found in the work of Fanelli(7) on the solubility of hydrogen sulphide in sulphur.

Solubility of gases in sulphur at 1 atm pressure and 120° C with the liquid sulphur exposed to the gas for different lengths of time

	10^5 × *Number of moles dissolved per 100 g of sulphur*		
	Exposure time		
	0·4 *h*	1·2 *h*	2·0 *h*
Air	0·9	1·7	1·8
N_2	0·7		1·4
He	0·5		0·7

From the similarity of the solubilities of nitrogen and air, it is apparent that there is no appreciable chemical reaction between the sulphur and the oxygen of the air in the time of the experiment. It is also very interesting to note that the ratio of the solubilities are similar to the ratio of the solubilities of the same gases in freezing water. The solubilities in sulphur are, however, about seven times less. Consequently, it should be much easier to remove the gases from sulphur than from water and this is what we have observed.

There has been some suggestion(8) that sulphuric acid is formed in sulphur when it is stored for long periods. One of our specimens that had been stored for six months was found to contain less than 0·001% sulphuric acid.

Atmospheric gases are appreciably dissolved by sulphur and can only be properly removed by fusions under a pressure less than 10^{-3} mm of mercury. High purity sulphur free of dissolved gases can now be readily prepared for use in physical measurements. Liquid sulphur will remain gas free only while it is under vacuum. It is possible that reported variations in a number of measurements of viscosity, surface tensions, etc., may be attributed to inadequate preparation and exposure to air during the measurements.

The author wishes to thank Dr. J. A. Morrison for helpful discussions and assistance in preparing the manuscript.

REFERENCES

(1) Bacon, R. F., and Fanelli, R. *Industr. Engng Chem.*, **34**, p. 1043 (1942).
(2) Threlfall, R., and Brearley, J. H. D. *Phil. Trans A*, **187**, p. 57 (1896).
(3) Kellas, A. M. *J. Chem. Soc.*, **113**, p. 903 (1918).
(4) Farr, C. C., and Macleod, D. B. *Proc. Roy.* (*London*), **97**, p. 80 (1920); **118A**, p. 534 (1928).
(5) Bacon, R. F., and Fanelli, R. *J. Amer. Chem. Soc* p. 639 (1943).
(6) Malus, C. *Ann. Chim. Phys.*, (7) **24**, p. 491 (1901).
(7) Fanelli, R. *Industr. Engng Chem.*, **41**, p. 2031 (194
(8) Mellor, J. W. *Comprehensive Treatise on Inorgani Theoretical Chemistry*, **10**, p. 88 (London: Longr Green and Co., 1947).

A smaller Haringx-type vibration isolating table

By J. A. Macinante, B.E., Division of Metrolo National Standards Laboratory, C.S.I.R.O., Sydn Australia

[*Note received* 10 *December*, 1957]

Haringx* describes a vibration isolating table in wh main mass on springs carries an auxiliary mass-s system, which acts as a "dynamic absorber" to reduc vibration of the main mass. The advantage claimed fo table in comparison with a single-mass table is that disturbed (e.g. when an instrument on the table is pulated) the two-mass system comes to rest more qu unless the single-mass table is heavily damped with sequent loss of efficiency in the working frequency rang

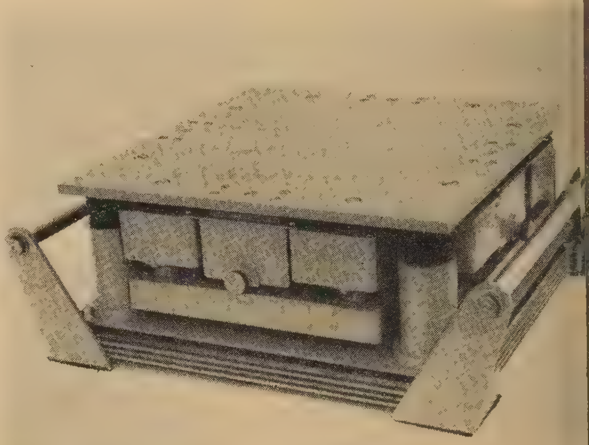


Fig. 1. The smaller Haringx-type table

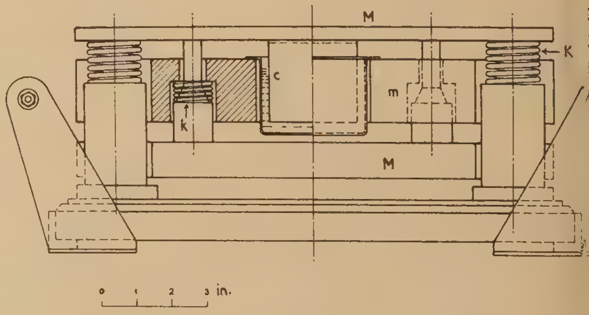


Fig. 2. Cross-section of the table

The general-purpose table described by Haringx req bench space of about 2 × 2 ft. This note describes a sm table, shown in Fig. 1, which was designed to meet a for a more compact table to carry only one or two galv meters. The new table uses only about 1¼ × 1¼ ft of be nain mass M (Fig. 2) is in two layers so that its centre ıvity may be located in the "elastic plane" of the four springs K to ensure that the various natural modes of tion will be uncoupled. The auxiliary mass m is on springs k seated on the rods which connect the two of the main mass. There is a liquid damping c between vo masses. Haringx suggests 2–4 c/s as a suitably low ance region for each mass-spring system in all modes bration, and the springs are designed for appropriate ontal as well as vertical stiffness to achieve this. ıgx nominates $M = m$ and derives certain optimum onships for the spring stiffness and the damping, but ıdicates that wide departures from these optima are issible. The new table has a top surface of $13\frac{1}{2} \times 13\frac{1}{2}$ in. ın overall height of 6 in. The added loading on the is not critical and in the design allowance was made vo galvanometers, each 6 lb and with centre of gravity above its base. The masses are each about 70 lb, and otal weight of the table about 170 lb.

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* Haringx, J. A. *Philips Tech. Rev.*, **9**, p. 16, 85 (1947)

attempt was made to design for a particular damping as a wide range is evidently permissible, and in any the damping is easily modified by changing the liquid. dampers are filled through a hole in the top plate and ed through a screwed outlet. The top plate was made removable without disturbing the auxiliary system. ying handles were added.

e effectiveness of the table in reducing steady-state tion is strikingly demonstrated by comparing the ce of a small dish of mercury on the table with that of nilar one on the bench. When the bench is vigorously ted by a mechanical vibrator, deep standing-wave rns appear in the mercury on the bench, but ripples in nercury on the Haringx table are hardly perceptible.

ıe table was reported by various colleagues (i) to isolate tively a sensitive galvanometer on a wall bracket on h the galvanometer previously was unusable, and (ii) to ove greatly the visibility of interference fringes from the ıce of a mercury pool which was supported on the ngx table; without the table the fringes could not be . Vibration tests were made with the Haringx table on ooratory bench to which was fixed a mechanical vibrator. both vertical and horizontal vibration in the range 0 c/s the displacement on the Haringx table was less one-tenth of that on the bench. Tests made with two ping oils (SAE 60 and 90) gave similar results.

ther tests on two types of bench to which were applied cal and horizontal impulses indicated satisfactory ction except when the natural frequency of the bench ation happened to be near the resonance range of the ingx table. In general, the Haringx table responded one or two cycles of its long-period, heavily damped, ıral vibration, upon which was superposed the attenuated ıer frequency component associated with the transient onse of the bench. Although the tests were not compre- sive, they showed that the small Haringx table effectively ıtes steady-state vibration at frequencies above the nance range of the table, as well as impulses, if the sient vibration frequency, a function of the mass and lity of the bench, is well above the resonance range of table.

cknowledgement is due to J. A. Taylor, formerly of the wing Office, and W. Hyett of the Workshop of the ional Standards Laboratory for helpful suggestions in the gn and construction of the table, and to Mr. J. Waldersee he Division of Metrology for the vibration and bump s.

Pot-core construction for a Hall multiplier

By D. J. Lloyd, B.Sc.(Eng.), Electrical Engineering Department, University of Bristol

[*Note received* 11 *December*, 1957]

A Hall multiplier is conveniently energized in the air-gap of a Ferroxcube (by Mullard Ltd.), pot-core assembly, with the plate stuck directly to one of the pole faces; this construction has some merits. The Hall plate is rigidly supported and can be ground to the desired thickness *in situ*. The Ferroxcube is a moderate thermal conductor and helps to conduct heat away from the Hall plate. The Q of the pot-core coil is high, and the magnetic circuit may be operated efficiently at higher frequencies than would be possible if it consisted of a laminated metal core.

The pot-core pole piece is first modified to provide outlets for the Hall plate leads. As it is often desirable to separate physically the output leads from the input leads to the plate, two grooves are cut in the curved surface of the pole piece. The position of one is such that its end is close to the existing hole in the component in its original state; the other groove is made diametrically opposite and a second hole is drilled close to the end of it. Details of these operations are shown in Fig. 1. If supersonic cutting equipment is not available the material may be worked reasonably quickly using a diamond tipped dentist's drill, with Teepol (by Shell Chemicals Ltd.) as the cutting fluid.

The length and breadth of the Hall plate are ground to the required dimensions and the points at which the leads are to be attached are prepared and tinned. The plate is now stuck to the pole piece using Araldite (by Aero Research Ltd.). After this has set, the plate is ground to the required thickness using emery cloth and water backed by a plane glass block, or other media to suit the Hall material. The leads are soldered to the plate and are brought out in pairs

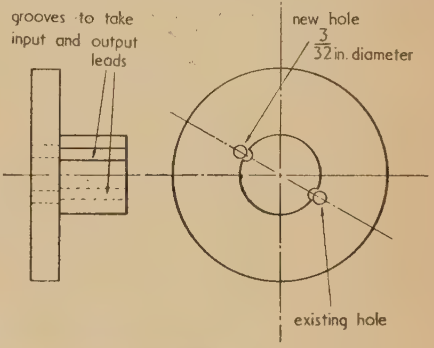

grooves to take input and output leads
new hole
$\frac{3}{32}$in. diameter
existing hole

Fig. 1. Details of modifications to part of Ferroxcube pot-core

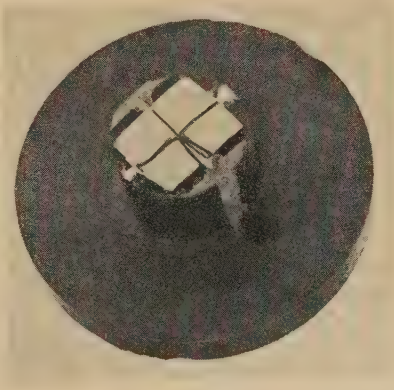


Fig. 2. Hall plate, mounted and complete with leads

through the grooves; Araldite may again be used to seal the leads if the construction is intended to be permanent.

Fig. 2 shows an indium antimonide Hall plate mounted on a type LA-11 Ferroxcube part (by Mullard Ltd.), as described above. The input leads to the plate are soldered to the shorter edges and are in the nearer groove, and the output leads leave the plate *via* the further groove. In this example, the leads are sealed into the grooves with Plasticine.

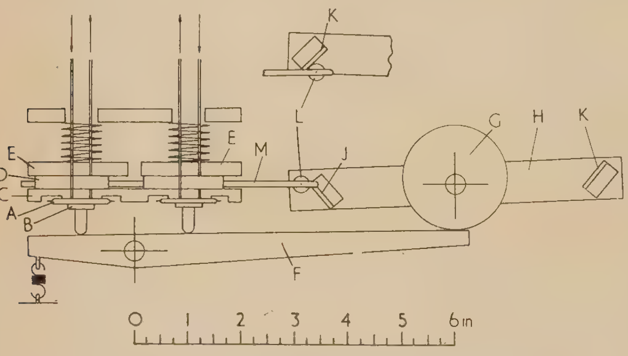
A constant volume pump for low flow-rates

By M. C. CORFIELD, M.A., Ph.D., S. DILWORTH, and G. HINES, Wool Industries Research Association, Torridon, Headingley, Leeds 6

[*Note received* 12 *December*, 1957]

An automatic instrument for the chromatographic separation and estimation of sub-micro quantities of radioactive derivatives of amino acids* has required control of the flow-rates of the organic solvents used for elution. The necessary pumping rates, 1 to 10 ml./h, are too small to allow satisfactory operation of a mechanical pump embodying ball valves. Peristaltic pumps employing rubber tubing† normally very useful for these pumping speeds, are unsatisfactory with the organic solvents required. The mechanical pump described here does not suffer from these disadvantages. Basically the mechanism consists of two diaphragm pumps, connected in parallel and working out of phase. Input and output connexions are made through a common slide-valve assembly of an unusual design.

Each diaphragm pump consists of two phosphor-bronze disks, cold-pressed into the shape of shallow dishes, soldered together at the rims to form a small capsule *A*. A brass cap *B* is soldered into a small locating hole in one side of the capsule, and the other side is similarly attached to a spigot turned on a brass sole-plate *C*. Inlet and outlet holes are drilled through the sole-plate into the capsules. The sole-plate has a lapped upper surface which bears the slide-valve assembly. This consists of two Teflon blocks *D* with plane, parallel surfaces, taking pressure from two lapped brass plates *E*. The latter carry inlet and outlet ports and connecting tubes and are spring-loaded in position. A hole in each Teflon block is positioned so that only when the blocks are in their extreme positions are the ports into the capsules open. The capsules are alternately compressed and expanded by means of a lever arm *F* driven by a constant velocity cam *G* on the shaft of a geared synchronous motor. A double



Arrangement of diaphragm pumps and valve mechanism
Inset. View of arm *H* on valve return stroke.

arm *H*, also attached to the shaft, has angled cam-plates
fixed to one side near the ends. These cam-plates alterna
engage a roller arm *L* projecting from the side of a
slide-plate *M* thereby imparting the necessary recipr
movement to actuate the valve mechanism. Each move
of the valves is completed while the cam shaft turns thro
10°. In this way while one capsule is filling up from
supply the other is pumping out to the sink and a contin
flow is maintained. The pumping-rate can be varied at
either by altering the speed of rotation of the cam-shaf
means of a gear-box, or by substituting another cam
different dimensions.

The construction of the Teflon blocks requires great
Rubbing on flat, shot-blasted brass plates was found to
suitable way of making them flat. Small particles of b
were removed by treatment with nitric acid followed
wash with water. The final planishing takes place du
the operation of the pumps. Wear in the valves is take
by the springs and only results in a more efficient liquid

The dead volume of each capsule is 0·3 ml. and
volume delivered by the maximum stroke is 0·1 ml.
pump is therefore useful for controlling chromatogr
employing solvents of continually changing composit
although very abrupt changes tend to be smoothed
The main advantage of the pump is that the valve mecha
requires no lubrication owing to the very low coefficien
friction of Teflon on brass. This fact makes it very u
for pumping solvents which dissolve oils and greases.
pump is also self-priming.

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* CORFIELD, M. C., FLETCHER, J. C., and ROBSON, A. *Chem. and Industr.*, p. 661 (1956).

† INGER BRATTSTEN. *Ark. Kemi*, **4**, p. 503 (1952).

A vacuum evaporator for radioactive and toxic metal

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ton, Middlesex

[*Note received* 19 *December*, 1957]

Vacuum evaporation is a technique much used in
Laboratory for the preparation of metallic diffusion s
mens. These consist of an inactive metal substrate o
which a thin layer of radioactive metal is evaporated. I
such as beryllium mirrors have also been made, the
paration of which requires the evaporation of a highly t
metal. It has been found that the usual evaporating cham
is unsuitable for use with radioactive and toxic metals beca
of the difficulty in decontaminating the chamber afterwa
It is the purpose of this note, therefore, to give a b
description of an arrangement which overcomes this difficu

The evaporating apparatus, shown in Fig. 1, is provi
with six electrodes, two of which (*B* and *C*) are shown.
electrodes are symmetrically disposed around the basep
centre, and they are fastened to the baseplate *A* by means
the lock nuts *D*. Six holes corresponding to the electr
positions are drilled in a Pyrex glass disk *E* which is t
fitted over the threaded portions *F* of the electrodes, to
on top of the lock nuts *D*. All surfaces of the disk
polished so that it can be easily cleaned. The portions *F*
the electrodes which protrude above the surface of the
E are shielded by the silica or glass tubes *G*, and the up
ends of these tubes are fused to leave only small holes thro
which pass the evaporating coils *H*. To obtain electri
contact between the coils and the electrodes, the ends of
coils are bent into a V-shape and pushed into the h
drilled down the axis of each electrode, as shown m
clearly in Fig. 2. This method of holding the evaporat
coils gives flexibility of adjustment for height, etc. The ax
holes in the electrodes also serve as a path for the evacuat

sidual gas which may be trapped between the O rings 2), which act both as additional vacuum seals and ical insulation of the electrodes from the baseplate. ugh it is preferable that the shields *G* be made of ; Pyrex can be employed, but it is then necessary to a refractory insulator, e.g. thermocouple tubing, en the coil wire and the Pyrex where the coil passes gh the top of the shield. Otherwise, the heat generated e wire during evaporation may cause it to fuse to the shield.

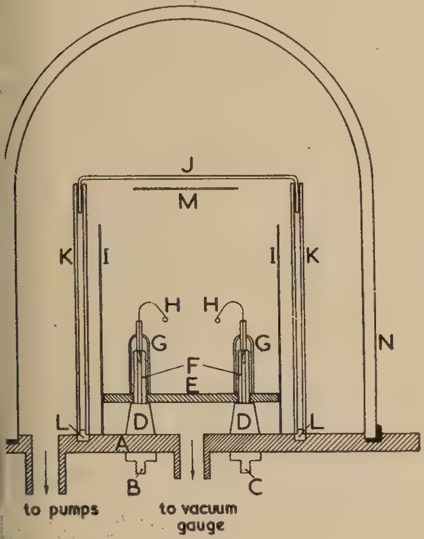


Fig. 1. Diagram of evaporating apparatus

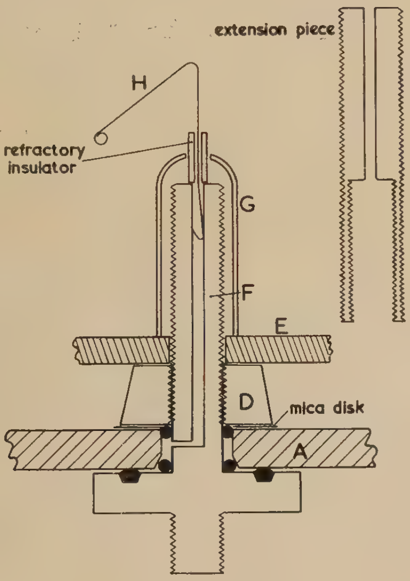


Fig. 2. Electrode detail

cylindrical metal foil or glass shield *I* is placed around circumference of the disk *E*, and an all-glass specimen er *J* is provided, fabricated from glass rod in the form n equilateral triangle. The three glass tubes *K*, of which are shown in Fig. 1 for clarity, fit on to the small poly- e plugs *L* which are inserted in the evaporator base- e, thereby assuring a rigid assembly. The shield *M* ects the specimen surface during the initial flashing of coils. Although evaporation is usually carried out in upward direction, the specimen to be coated may, if ed, be placed upon the glass disk *E*. The height of the orating coils *H* can be adjusted by moving the coils up and down the axial holes in the electrodes or, alternatively, extension pieces may be fitted to the electrodes as shown in Fig. 2. In this case a set of longer shields *G* must be used. Facilities for cleaning the specimens by glow discharge are available if required, the specimen being used as one electrode.

The parts of the evaporating chamber which become contaminated in use are the shields *G*, *I* and *M*, the disk *E*, and the upper portions of the specimen carrier *J* and the glass bell jar *N*. The glass and silica portions of the apparatus are easily decontaminated, and the shields *I* and *M*, if constructed of metal foils, may be scrapped after use.

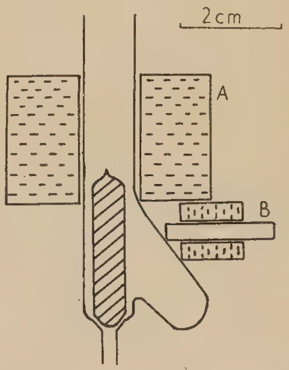
The work described above has been carried out under the general research programme of the National Physical Laboratory, and this note is published by permission of the Director of the Laboratory.

A filtration cut-off for use at low temperatures

By P. J. H. Carnell, B.Sc., and G. W. A. Fowles, B.Sc., Ph.D., Chemistry Department, University of Southampton

[*Note received* 31 *January*, 1958]

While operating a chromatographic column between −35 and −80° C we had trouble with the normal type of silicone-greased stopcock. Since the stopcock had to be immersed in a low-temperature thermostat containing ethanol, the silicone grease was gradually attacked by the ethanol and vacuum conditions could not be maintained inside the column. The tedium of operating a stopcock under these conditions led us to develop the magnetic cut-off shown in the figure. Since the temperature of the column had to be carefully controlled, it was essential to avoid producing appreciable amounts of heat in operating the cut-off, and we did this by having two solenoids, a "lifting" one *A*, and a "deflecting" one *B*. When the cut-off is to be opened, the "magnetic" valve is lifted by solenoid *A* and then deflected into the side pocket by solenoid *B* (with solenoid *A* off); the valve is replaced in its seating by lifting with *A* and then dropping into place. Heat is thus dissipated by the coils only during the brief time required for opening and closing of the valve.



Magnetic cut-off

The efficiency of the valve depends, of course, on its ground seating, and we found that with a ground surface of 4–5 mm length, the valve operated perfectly in liquid ammonia at −50° C over many hours. The ground seating is not greased, since the valve is used to cut off the flow of liquid rather than maintain a considerable pressure difference; in this respect, the cut-off has a further advantage over a greased stopcock, where contamination of the eluant by grease is difficult to avoid. There seems to be no reason why this cut-off should not be used with equal success for filtrations well above room temperature.

Correspondence

Obtaining rate thermal curves by a capacitor method

The examination of phase changes by thermal analysis, using a thermocouple as the temperature measuring device, involves precision potentiometry and accurate time measurement, principally in order to obtain accurate values for the rates of heating or cooling. Such experiments, if at all prolonged, incur much operator fatigue which can be reduced somewhat by using a "defined interval" type potentiometer and a two stop-watch technique or some form of recording chronometer. Another possible method, however, is to measure separately the temperature of the specimen and its rate of heating or cooling. The former need be measured only to the nearest 0·25° C even for precision work, and this can be achieved directly using a mirror galvanometer.

The present note describes the measurement of the rates of heating and cooling of zinc by measuring the charge or discharge current of a capacitor.

Fig. 1 is a simplified form of the circuit given in Fig. 2, which was used in the experiments. If the hot junction of the chromel–alumel thermocouple is heated at a uniform rate

$$dE/dt \simeq a = \text{constant} \qquad (1)$$

where E is the output voltage of the thermocouple and t is time.

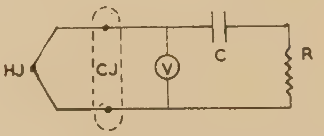


Fig. 1. Simplified diagram of electrical circuit

R, Universal shunt-Paschen galvanometer network. Other symbols as in Fig. 2.

Therefore, the current flowing into the capacitor is

$$i = aC\left[1 - \exp\left(-\frac{t}{RC}\right)\right] \qquad (2)$$

For a rate of heating of 1° C/min

$$a \simeq 0{\cdot}67 \times 10^{-5}\ \text{V/s}$$

Therefore, when $t \gg RC$

$$i = aC = 0{\cdot}67 \times 10^{-2}\ \mu\text{A}$$

Therefore the rate galvanometer must be sufficiently sensitive to give a large enough deflexion (e.g. several centimetres) when passing approximately 10^{-2} μA. A Cambridge, high sensitivity, moving coil galvanometer (2·8 kΩ coil resistance) would be sufficiently sensitive to meet this requirement but suffers the disadvantage of having an undamped period of about twenty seconds. In earlier work a Cambridge 450 Ω, short period (3 s undamped), moving coil galvanometer had been used as a rate galvanometer in the circuit shown in Fig. 2. Under these conditions, mathematical analysis had predicted a period of twenty seconds and this was confirmed by experiment. Therefore, the Cambridge high sensitivity galvanometer would be expected to have a period in the region of one minute when used in this circuit. This response period is much too long for thermal analysis.

A Cambridge Paschen moving-magnet galvanometer used as the rate galvanometer when it became available. had the dual merit of high sensitivity and damping indep dent of the external electrical circuit. In the present w the high resistance coils were placed in series, in order give maximum current sensitivity, and the galvanometer placed in parallel with a universal shunt. Thus when furnace was rapidly heated or cooled to any desired temp ture, large deflexions of the Paschen galvanometer coul avoided by adjusting the universal shunt. The time cons of the capacitor-universal shunt combination was two seco

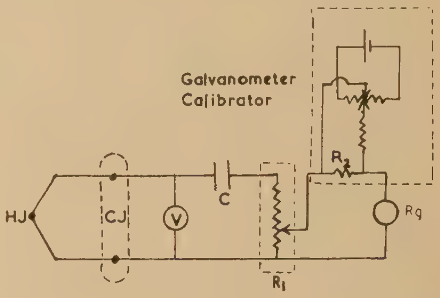


Fig. 2. Electrical circuit diagram of experimen apparatus

HJ, *CJ*, hot and cold junction of chromel/alumel thermocoup
V, Unipivot millivoltmeter (200 Ω); *C*, capacitor 1000 μ
Rg, Paschen galvanometer, 12 kΩ; R_1, universal shunt, 1780
R_2, less than 1 Ω.

The galvanometer calibrator was included in order to al rates of heating or cooling to be calculated directly fr circuit data. The calculated and experimental values w in substantial agreement.

The capacitor had been measured previously and 1000 ± 5 μF. The soakage of the dielectric had been fo to be negligible under the experimental conditions, exc when the rate of change of thermocouple e.m.f. was much greater than that equivalent to 1° C/min.

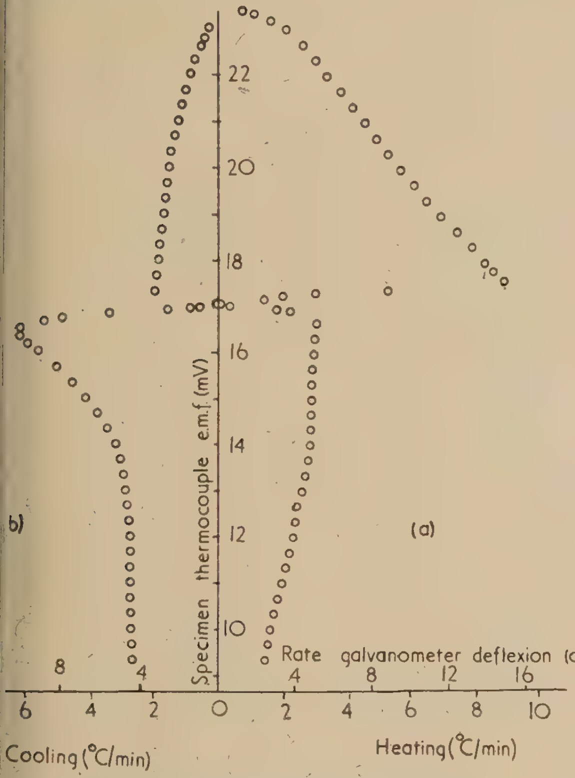
The temperature of the specimen was measured usin Unipivot millivoltmeter with full-scale deflexion equivalen approximately 40 mV. For more accurate work this ins ment could be replaced by a mirror galvanometer.

The whole of the measuring apparatus was supported paraffin wax blocks on an earthed copper plate. The furn frame was separately earthed, and an earthed nickel sle was placed round the specimen to prevent thermic leakage from the furnace heating element passing to thermocouple.

Spurious thermal e.m.f.'s in the measuring circuits w reduced, as far as possible, by carefully selecting compon and then shielding them from draughts in the assem apparatus. This did not entirely eliminate thermal e.m. but they were small and their effect was nullified by adjust the zero of the rate galvanometer scale to coincide with electrical zero of the galvanometer.

The zinc was held in a fireclay crucible placed in a c ventional tube furnace. The electric power supply to furnace was increased or decreased as required by unifor rotating the commutator of a Variac by means of an elec or. The thermal capacity of the furnace was large enough nooth the transient heating or cooling effects due to the ut voltage increments from the Variac (i.e. due to the number of turns on the Variac winding).

ne experimental results obtained are shown in Figs. 3 4. Figs. 3(*a*) and (*b*) show heating and cooling curves ined from observations of the rate galvanometer and . 4(*a*) and (*b*) show similar curves obtained from the sured time interval necessary for the unit change of xion (identical with 8° C approximately) of the Unipivot voltmeter.



ig. 3. Direct rate heating and cooling curves for zinc

is difficult to measure these time intervals accurately e unit deflexion, which is about ⅓ mV, is about 1–1·5 mm, it is immediately apparent that the two curves are similar orm. The direct rate curves can be compared in smooth- with those obtained using precision potentiometer niques.

n Fig. 3(*a*) the progressive increase in heating rate between and 13·3 mV was due to the establishment of an equili- m between the rate of heating of the furnace and the rate ncrease of power input from the Variac. Melting occurred at 17·07 mV, and because about 150 g of zinc had been used the duration of isothermal melting was 20–30 min. During this time the Variac output voltage had been allowed to increase uniformly and therefore the furnace temperature had risen significantly. This accounts for the rapid rate of heating over a large temperature range after melting.

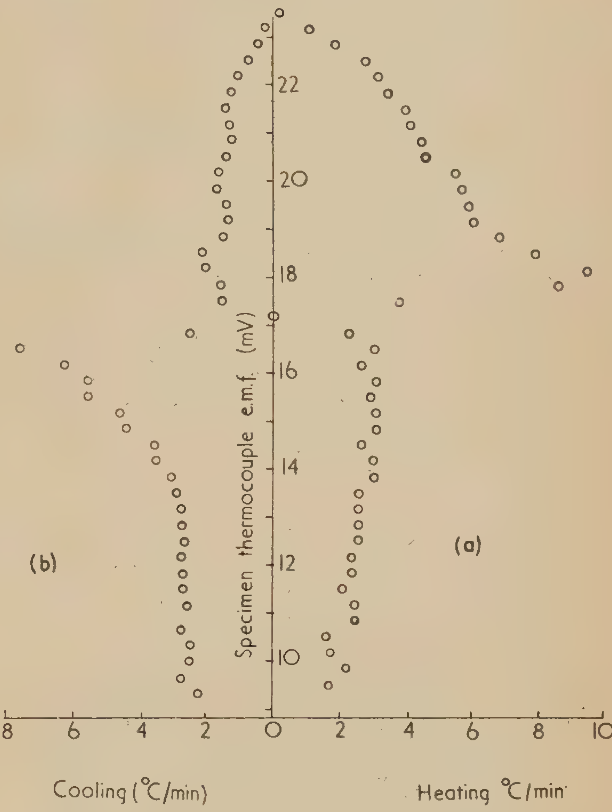


Fig. 4. Rate heating and cooling curves for zinc obtained from inverse rate measurements

Fig. 3(*b*) shows a very conventional rate cooling curve. Freezing occurred at 17·07 mV, followed by a conventional "swingback" during which the specimen cooled rapidly in order to establish an equilibrium cooling rate with regard to its surroundings.

We wish to thank Mr. C. Handford for making available earlier unpublished work on this technique.

Applied Chemistry Dept.,
College of Technology,
Manchester.

B. GREGORY
G. BULLOCK*
[18 February, 1958]

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* Now at University of Birmingham.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impr
products. The Institute of Physics assumes no responsibility for the statements given below: information for these has
taken from literature supplied.

Ultra-high vacuum pump. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A.

The Evapor-ion pump is designed for producing vacua down to 10^{-9} mm in non-cyclic systems. The principle of the operation is that titanium wire is fed on to a post heated by electron bombardment from a filament. The titanium evaporates and, upon striking the cooled pump wall, condenses as a thin layer. This acts as a getter for active gases, which comprise over 99% of the residual air. As each layer of titanium becomes chemically saturated, a fresh layer is deposited. The inert gas molecules are ionized by electrons emitted from the filament. The electric field of an accelerator grid between the filament and the walls repels these ions and drives them into the titanium layer, where they are buried by subsequent titanium evaporation. The pumping speed for nitrogen is of the order of 2000 l/s.

Liquid level detector. Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, near Reading, Berks.

The level detector illustrated in the figure consists of a yoke and indicator unit connected by a cable. One arm of the yoke carries a radioactive source and the other a Geiger counter. The yoke is held so that it spans the vessel under inspection. When it is moved up the vessel, the amount of radiation reaching the counter changes when crossing a liquid-gas interface. The instrument will operate either from the mains or from a 6 V battery. The yoke is adjustable to suit vessels up to 10 in. diameter.

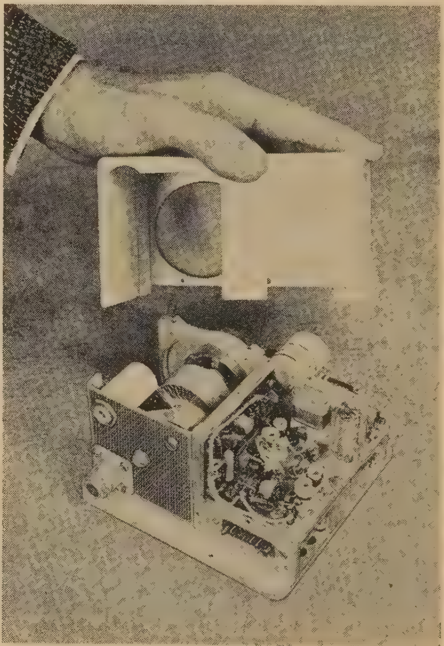
Checking level of liquid carbon dioxide in fire extinguishers by radioactive gauge

Lead–acid storage cells. Oldham and Son Ltd., Den
Manchester.

The capacity of a storage cell of given size is mainly d
mined by the amount of active material which can be
tained in the plates. The life of the battery is, in part, d
mined by the ability of the grid structure of the pos
plates to retain the active material. A new type of pos
plate, designated the Pg plate, has been introduced to
these requirements. This consists of a number of thin P.
tubes each extensively perforated to provide a great acc
bility of the electrolyte to the active material. Each P.
tube is lined with a woven glass fibre sleeve, the asser
being centred on a feathered X metal spine. The a
material is closely packed into the space between the s
and the glass fibre sleeve. It is stated that by reason of
thinness of the P.V.C. and the glass fibre wall, a gre
volume of active material can be packed into each t
This is an important factor contributing to greater capa
In use, the glass fibre sleeve becomes securely embedde
the active material, which is therefore positively retaine
contributing to longer life. The greater accessibility of
electrolyte to the active material afforded by the perfor
in the P.V.C. tube gives a lower internal resistance.

200-W phase-modulation transmitter. Texas Instruments
6000 Lemmon Avenue, Dallas 9, Texas, U.S.A.

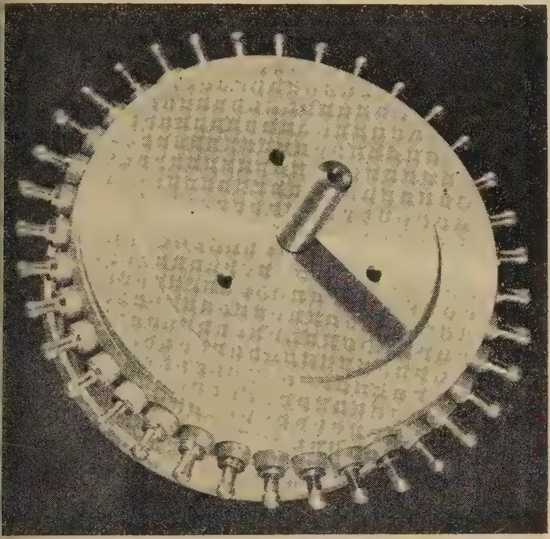
The phase-modulation transmitter shown in the figur
specially designed for telemetering missile flights. It is c
plete in a single unit occupying only 67 in.^{3} space. Tr



Transistorized 200-W phase-modulation transmitter on is in the 215–235 Mc/s band, with a claimed frequency lity of ±0·01% at temperatures up to 71° C. High erature silicon transistors are used in the oscillator, ɔ modulator, video amplifier and frequency doubler its. The output stage utilizes a stacked ceramic tetrode considerable excess capacity, and tubes are also used as rs and multipliers.

i-tap linear potentiometer. General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

w precision linear potentiometer, which can readily be ted to provide a wide range of non-linear functions, has developed. This device has an electrical angle of 340°, a winding tapped at 10° intervals and the connexions ı to turret-type terminals spaced round the potentio- r body. It is very suitable for producing non-linear



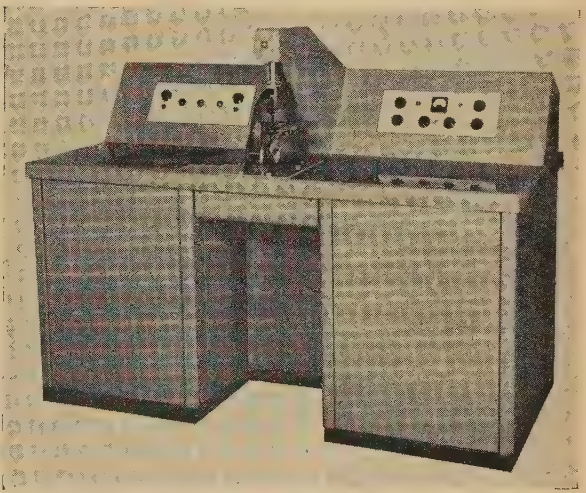
ecision linear potentiometer with tappings every 10 deg

tions by connecting shunt resistors across sections of the ling. The large number of taps enables a wide range of tions to be accurately reproduced. The potentiometer ıted to be of robust construction and low starting torque. ın be supplied in a range of resistance values from 1 to k Ω.

ıg-spot microscope, particle counter and sizer. Cinema Television Ltd., Worsley Bridge Road, Lower Sydenham, London, S.E.26.

basis of the instrument is a flying-spot microscope. On face of the scanning cathode-ray tube is produced a line diagonal sequential scan raster, which is imaged n through a conventional optical system to scan that ion of a slide contained within the field of the objective used. The light passing through the slide is modulated ccordance with the density variations of the object. e light variations are passed to a multiplier photocell e they produce an electrical signal to modulate the monitor cathode-ray tube, which has a raster in synchronism with that of the scanning tube. On the monitor tube is seen an image of the slide at magnification adjustable between ×200 and ×8000 and with a resolution of 0·1 μ.

The second function of the instrument is to count automatically the number of particles contained within the field of the objective. To understand how this is done, consider the case of a single particle on the slide. When scanned by the flying-spot, an intercept pulse is produced which passes to a Quantizer. This unit will pass the pulse only if it is greater than a pre-determined level and thus eliminates counts from spurious particles and random noise. The pulse from the quantizer passes through a gate, normally open, to a cold-cathode counter tube. The gate is controlled by a summation circuit whose inputs are the output from the quantizer, and this same output delayed by an interval equal to the line scan time. When the flying-spot scans the particle for the second time on its next line scan, the same sequence of events occurs but with one important difference. The summation circuit now has a condition of coincident inputs due to the pulse from line 2 plus the delayed pulse from line 1. This state produces an inhibiting pulse which shuts the gate and prevents the second count being recorded from the same particle. This condition exists for any number of particles along one line scan and thus in any given field each particle is counted only once. It should be noted that false counts will be recorded if the particle presents a re-entrant to the direction of scan, or if particles are not separated by at least two picture elements. The counting time is 8 s. The minimum particle size which can be counted is 0·6 μ and a repetitive count accuracy of ±2% is claimed.



Combined flying-spot microscope, particle counter and sizer

The third function of the instrument is to size particles automatically. This is performed by a sizing unit which produces a pulse of selectable width corresponding to a given size of particle on the slide. All particles less than the size selected will not be recorded during a field count. Thus, by successive counts with different minimum sizes, a complete size analysis of the field can be obtained. The size range covered is 0·6 to 160 μ in 60 increments.

New books

Semiconductor thermoelements and thermoelectric cooling. By A. F. Ioffe. (London: Infosearch Ltd., 1957.) Pp. 184. Price 42*s*.

Reports of Russian work on thermoelectric applications have played a large part in stimulating the recent increase of interest in this topic. The inaccessibility of the original papers to those who do not read Russian makes the publication of this work in English very welcome. The author, after a long and distinguished career in other branches of physics, has spent the last few years directing a large group of scientists studying this subject. The book explains their approach and describes their results and conclusions.

In fact this is not one book but two, and in consequence there is a certain amount of duplication. The first part deals mainly with the thermoelectric generation of electricity, and the second with thermoelectric refrigeration only. The treatment of each section is almost self-contained and follows a similar pattern. The author firstly describes the thermodynamics of the thermoelectric effects and of devices using them, and then shows how the use of semiconductors enables higher "figures of merit" to be obtained. At this stage, there is an account of the theory of conduction processes in semiconductors which, while adequate for physicists, would probably not be readily understood by, say, a refrigeration engineer. Experimental methods and results on a number of semiconductors come next, and both parts finish with descriptions of working thermoelectric devices. The performance of these suggests that while the generators are probably only useful in the absence of other sources of electric power, the refrigerators already show greater coefficients of performance than the widely used absorption type.

J. E. Parrott

Machinery's annual buyers guide. 29th ed. 1957–58. (London: The Machinery Publishing Co. Ltd., 1957.) Pp. 993. Price 10*s*. 6*d*.

In addition to 728 pages of manufacturers' names listed under product headings and lists of their addresses and agents this volume contains French–English, German–English, Russian–English and Spanish–English glossaries. Also included are lists of professional and scientific institutions, trade associations, research organizations, etc., and some useful tables of technical data.

Instrument encyclopedia. Compiled by E. W. Battey. Consultant Editor, A. Linford. (London: The Herbert Publishing Co. Ltd., 1958.) Pp. xx + 292. Price 63*s*.

This encyclopedia classifies and indexes more than three thousand products of 1740 British manufacturers of instruments, components and accessories. It will be a useful reference work for those in the instrument industry or those needing to use instruments in their work. The first eleven pages are devoted to an alphabetical index of the pro referred to in the body of the volume. Next follows a 28- alphabetical list of "definitions, descriptions and explana of terms in common use and relating to the instru industry." The selection here seems to have been some arbitrary and many terms in use such as transistor, thyra pulse generator and oscillator are not in the list although may appear in other sections of the work. The alphab index to the names and addresses of the manufacture followed by a list giving the geographical location of ove agents. The buyers' guide gives the names of the supplying the various pieces of apparatus and runs to pages, it is divided into the following eight groups: labora medical research; optical, ophthalmic; electronic, nucle electrical; engineering; automation, process control; a sories, components, equipment; nautical, aeronautical veying. The last section is a composite catalogue of names, giving the name of the firms with which ea associated. Some of these appear also in the "definiti section.

This volume would have been improved by more ca sub-editing and attention to detail such as consisten spelling. Its use would be facilitated by having the nu and title of each section as running heads and either b provision of a thumb index to them or by printing different sections on tinted paper.

H. R. La

Definition and significance of the flow coefficient in accele flow, with special reference to metering devices. By Redding. (Chislehurst: B.S.I.R.A., 1957.) Pp. ii Price 5*s*. 6*d*.

This pamphlet, which is a reprint of a paper from the *Jo of Electronics and Control*, is addressed not only to specialists, but also to students and others coming fre the subject.

British Journal of Applied Physics

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A mechanical version of the Smith Chart

By J. E. KNOWLES, B.Sc.,* British Scientific Instrument Research Association, Chislehurst, Kent

[*Paper first received* 2 *September, and in final form* 16 *December*, 1957]

A modification of the Smith Chart has been devised for the purpose of computing the transmission characteristics of non-absorbing optical or electrical multi-element filters. The conventional printed chart is replaced by a system of mechanical linkages together with a spiral computing element. The computer is more accurate, faster and less laborious to use than the orthodox chart.

Smith Chart(1,2) has long been used for calculating the mission (or reflectivity) of optical(3) or electrical non-rbing filters. The computations for a multi-element are very laborious, but the calculating process may be erated without any loss in accuracy by using the ıanical computer based on the principles of the Smith 't which is described below. Like the chart the computer be used for the calculation of both electrical and optical smissions: for any angle of incidence in the latter case. hasis will, for clarity, be laid upon the optical applica- of the instrument, and it will be assumed that the er is familiar with the use of the orthodox chart.

will be remembered that application of the chart to i-layer problems involves two types of operation:

) rotating the radial arm through an angle θ equal to $4\pi nd/\lambda$ radians, where nd is the optical thickness of the layer under consideration. θ may be written as $4\pi ndv/c$ and so will, for convenience, be referred to as the "reduced frequency" associated with the layer (or length of transmission line);

) multiplying the complex number so obtained by a positive number, generally the ratio of two refractive indices or admittances ("normalizing"), and plotting the product on the chart.

nis latter operation is laborious and inherently inaccurate, e it involves the location of a point on a non-linear rdinate net. The design of the computer was directed naking this operation an entirely mechanical one, thus ı simplifying it and enhancing the accuracy of the results. s a preliminary to the design of a mechanical computer ocus on the chart of a point $(R + jX)/Z_0$ when multiplied real positive number n was investigated. By the appli- on of co-ordinate geometry it was shown that the locus an arc of a circle passing through the extremities of the axis. A simple linkage was devised so that if any point co-ordinates $(R_1 + jX_1)/Z_0$ was located by a pointer p he chart, the linkage would constrain the movement of pointer to the locus $n(R_1 + jX_1)/Z_0$. This linkage is vn in Fig. 1 (ignore, for the moment, the broken line). ital letters are used to designate the arms of the linkage small letters the associated pivots. The figure represents Smith Chart with its radial arm C pivoted at c the centre ne chart. The two arms A and B are slotted along their ths to receive the pins a and b, which are located at the emities of the real axis. A and B are pivoted at their on the pivot p and they can be clamped together so the angle ApB is fixed: p can be independently clamped where along the length of C. If we suppose that p is positioned at the point $(R_1 + jX_1)/Z_0$ on the chart and that A and B are clamped together whilst p is free to move along the slotted arm C, then if the linkage is moved manually p will be constrained to follow the arc of a circle through a and b: i.e. the locus $n(R_1 + jX_1)/Z_0$.

The next problem to be considered is: "If p is at the point $(R_1 + jX_1)/Z_0$, how may it be moved to the point $n_1(R_1 + jX_1)/Z_0$ where n_1 has now a known arithmetical value?" Suppose that to the end of the arm B is attached a perpendicular arm D (Fig. 1, shown with a broken line). Then wherever p may be on the circle corresponding to a given value of the real component of the impedance $(R_1 + jX_1)/Z_0$, then since the angle DpB is a right angle, D will always intersect the real axis at the point R_1/Z_0. Thus, if p is at the point $(R_1 + jX_1)/Z_0$, to proceed to the point $n_1(R_1 + jX_1)Z_0$ A is clamped to B so that the angle ApB is fixed and the linkage then moved until D intersects the real axis at the point n_1R_1/Z_0. It may be seen that the resistance and reactance circles printed on the Smith Chart no longer play any part in calculating the transmission of a filter and may be omitted, leaving only the real axis with the values of R/Z_0 marked along it.

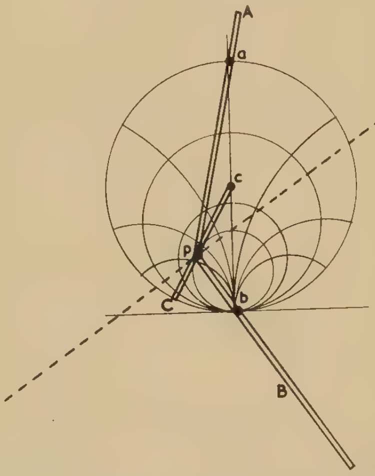

Fig. 1. The linkages shown superimposed on the Smith Chart

This operation of multiplication is further facilitated by the provision of a spiral computing element which is drawn on a disk of radius ab, pivoted at its centre b and which is placed under the linkages so that it supports them (see Fig. 2). On the periphery of the disk are engraved values of R/Z_0, and the geometry of the spiral is such that when a particular value of R/Z_0 is opposite to a the intersection of the spiral

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Now at Mullard Research Laboratories, Salfords, Surrey.

with the line *ab* (i.e. the real axis) is at the point R/Z_0 on the real axis. Furthermore the values of R/Z_0 are plotted logarithmically so that rotation of the disk through a given angle always multiplies (or divides) the indicated value of R/Z_0 by the same factor. A fixed logarithmic scale similar to that on the periphery of the disk (but in the reverse sense) is fixed adjacent to the lower edge of the disk: this scale will be referred to as the "multiplication scale." The multiplication scale as drawn covers the range 0·25 to 4·0, which is sufficient for optical calculations, and is arranged so that the number 1·0 lies on *ab* produced. To perform a multiplication by, say 1·70, the disk is rotated until the point on its circumference which was opposite 1·0 on the multiplication scale is now opposite 1·70. In the instrument a clutch mechanism is used to carry out this operation.

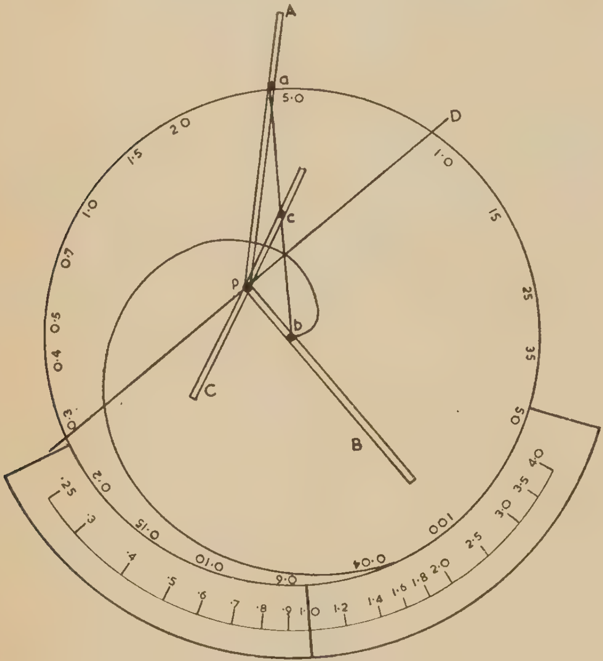

Fig. 2. Diagrammatic plan view of computer

We may now consider the application of the computer as drawn diagrammatically in Fig. 2 to the calculation of the transmission of a non-absorbing multi-layer filter.

THE OPERATIONAL SEQUENCE

(1) Set *p* at the appropriate point on the real axis. Lock *p* to *C*, unlock *A* from *B*.

(2) Rotate *C* through an angle corresponding to the reduced frequency, $nd \times 720°/\lambda_1$ associated with the first layer. Rotate disk until the spiral intersects the point where *D* crosses the line *ab*. Multiply the value of R/Z_0 so obtained by rotating the disk as described in the previous section. Clamp *A* to *B*, unclamp *p* from *C* and push linkage until *D* again lies over intersection of spiral and line *ab*.

(3) Unclamp *A* from *B*, clamp *p* to *C* and rotate *C* through the angle corresponding to the reduced frequency of the next film.

(4) Repeat (2) and (3) until the multi-layer has been traversed. Finally the transmission may be read off a scale engraved on the arm *C*.

It will be noticed that the proposed system removes
previously mentioned source of inaccuracy arising from
process of locating a point on a non-linear co-ordinate

THE PRACTICAL DESIGN OF THE COMPUTE

The complete instrument is shown in plan in Fig. 3
in cross-section in Fig. 4. A plywood baseboard carried
pivots *a* and *b*, the distance between their centres being 2
so that the computer may be considered equivalent
Smith Chart of that diameter. The disk on which the s
is drawn was carried on a spindle of which the pivot *b*
an extension. A piece of thin celluloid sheet about one
wide was stretched between *a* and *b* above the disk. A
was engraved along the centre of this strip so that as descr
previously, the intersection of this line with the spiral sho
the position on the real axis of the particular value of
engraved near the edge of the disk, which happened t
opposite to *a*.

On the disk, and celluloid, rested the T-piece mad
Perspex, comprised of the arms *B* and *D*. The upr
hitherto referred to as *B*, of the T-piece was slotted alon
length to receive the pin *b*. The pivot *p* was rigidly atta
to the upper surface of the T-piece. The slotted arm *A*,
of Perspex fitted over the pin *a* and was pivoted at its ext
end to *p*. The middle section of *p* was threaded so tha
turning a spider nut through a small angle, *A* could be qui
clamped to the T-piece.

The bearing for the pivot *c* was carried on a Perspex br
so that it was supported above the centre point of the
axis. The bridge also carried the reduced frequency
which was in the form of a celluloid ring marked in deg
To permit the pivot *p* to "slide through" the pivot *c*, *C*
constructed of an upper and a lower section, also of Pers
held apart by spacers. The upper section of *p* was piv
in the lower half of *C* whilst the pivot *c* was free to slide a
a slot running the length of the upper half of *C*. To en
c to be clamped at any point along the length of *C*, *c*
loaded by a spring *S* (Fig. 4) so that whilst *C* was al
able to turn freely about *c* it could not slide along it u
the spring pressure was released by depressing the butto
To avoid dead centre difficulties and to ensure that *C* al
intersected the reduced frequency scale, the length of *C*
doubled with *p* pivoted in the centre of the bottom
(see Fig. 2). The transmission scale engraved on the
side was thus duplicated, running from 100% transmis
at the centre of *C* to 0% at the ends. At the end of a c
putation the transmission was read off opposite the ce
pivot *c*, a cursor being mounted on *c* for this purpose,
facilitate the setting of *p* over the intersection of the sp
and real axis at the start of operations *p* was made in
form of a tube instead of a solid bolt, the internal diam
being about $\frac{3}{32}$ in.

It has been mentioned that a clutch mechanism was
to turn the disk in the "normalizing" operation, and this
now be described. The disk carrying the spiral was suppo
by a spindle passing through the base plate—the upper
of this spindle formed the pivot *b* and the lower end of
spindle carried a large thin metal disk which was locked t
The spindle also supported just above this disk one arr
a pair of levers with a pincer action (see Fig. 4): this
was able to rotate freely about the spindle. The o
("handle") end of the arm carried a cursor which mo
over the multiplication scale. When this end of the pi
was grasped between finger and thumb the jaws of the pi
gripped the lower disk, so that as the cursor was trave

the scale the thin metal disk was rotated through the sponding angle, turning the spiral-carrying disk with it. to multiply the number indicated on the real axis by, ·70, the handle at its rest position with the cursor at n the scale was moved until the cursor arrived at 1·70 e multiplication scale. The hand grip was then relaxed, locking the pincer from the lower disk, and the cursor ned to 1·0. To assist its return to the rest position it arranged that when the cursor was very near 1·0 it ked" into place.

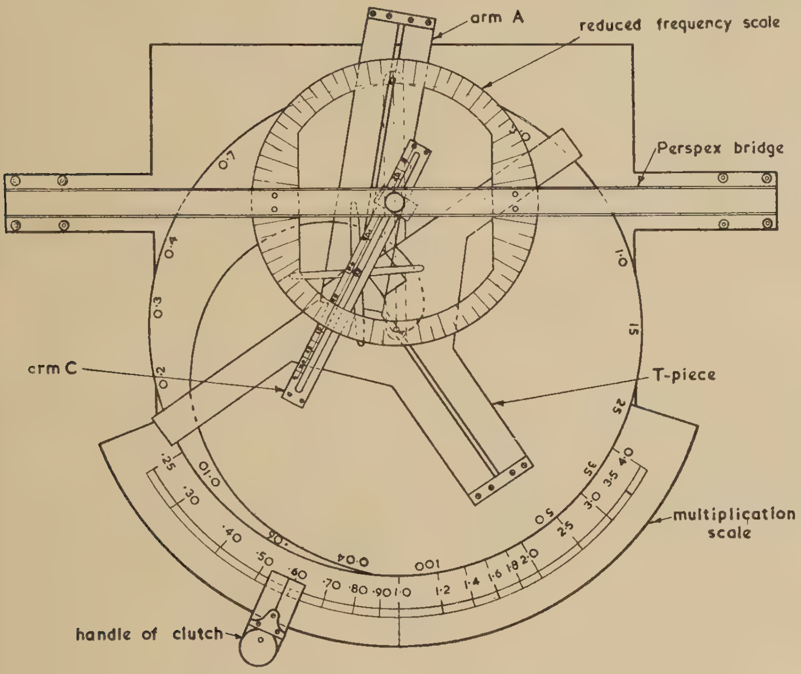
arm A
reduced frequency scale
Perspex bridge
arm C
T-piece
multiplication scale
handle of clutch
0·7
0·4
0·3
0·2
1·0
15
25
0·10
·25
·30
·40
·50
·60
·70
·80
·90
1·0
1·2
1·4
1·6
1·8
2·0
2·5
3·0
3·5
4·0
0·04
100
50
35
40
25
30

Fig. 3.
Plan view of computer

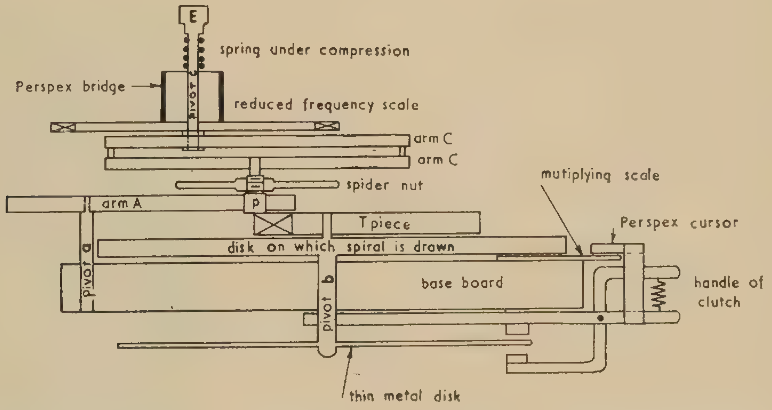
E
spring under compression
Perspex bridge
pivot p
reduced frequency scale
arm C
arm C
spider nut
arm A
p
T piece
disk on which spiral is drawn
mutiplying scale
Perspex cursor
pivot a
base board
pivot b
handle of clutch
thin metal disk

Fig. 4. Diagrammatic cross-section of computer (not to scale)

will be appreciated that for mechanical reasons there some places on the impedance circle where p cannot be ted. The inaccessible areas are in the immediate vicinity a and b and near the periphery of the chart. This has sed very little difficulty since these areas of the Smith rt are seldom used; obviously the situation would be roved by scaling up the computer, but keeping the pivot s unchanged.

THE OPERATION OF THE COMPUTER

he operational sequence given above may now be amplito describe the application of the computer to finding the transmission characteristic of a typical optical filter. As a test of accuracy the results given by the computer were compared with those obtained by an exact method. Dr. W. Weinstein, of Imperial College, University of London, kindly supplied a set of transmission values for a typical filter: these values had been computed by the matrix method and were correct to five significant figures.

The filter design considered for this exercise was a seven layer system of the form glass *HLHLHLH* air, the refractive index of the glass being taken as 1·523, that of the high index layer 2·30, and that of the low index layer 1·35, all the dielectric layers being of equal optical thickness. As an example let us take the calculation of the transmission for the reduced frequency $\theta = 225°$.

(1) Rotate disk until the figure 0·66 (i.e. 1·52/2·30) is opposite the pivot *a*. The intersection of the spiral with the real axis is now at the point $R/Z_0 = 0{\cdot}66$. Loosen the spider nut so unlocking *A* from the T-piece and depress the button *E*, so freeing the arm *C*. Push the linkage until the centre of pivot *p* is over the intersection. This operation is facilitated by the fact that *p* has a central sighting hole, as described earlier. Release the button *E*.

(2) Rotate C to the position 225° on the reduced frequency scale. Tighten the spider nut, thus locking A to the T-piece. Rotate the disk until the spiral passes through the intersection of the T-piece with the real axis. Grasp the handle of the clutch and move the cursor until it is over 1·70 (i.e. 2·30/1·35) on the multiplication scale. Depress the button E and move the linkage until the T-piece again intersects the spiral on the real axis.

(3) Unlock A from T-piece and release button E. Read off the position of C on the reduced frequency scale $-197\cdot5°$ and rotate C to $197\cdot5 + 225 = 422\cdot5 = 62\cdot5°$ on the scale.

(4) Repeat these procedures until the complete multilayer system has been traversed, finally reading off the transmission from the scale engraved on the arm C.

Table 1. *The working of a calculation*

θ	1·70	0·587	1·70	0·587	1·70	0·587	2·30	T%
		197·5	35·1	228·0	60·1	252·6	85·2	
225		225	225	225	225	225	225	67·6
		———	———	———	———	———	———	
		422·5	260·1	453	285·1	477·6	310·2	

To avoid becoming "lost" in the middle of a calculation the work may be conveniently set out in Table 1.

The transmission values supplied by Dr. Weinstein are compared in Table 2 with those obtained with the computer and a Smith Chart of equivalent size, i.e. 10 cm radius.

Table 2. *Comparison of transmission values*

θ	T% *accurate*	T% *computer*	T% *Smith Chart*
180·0	4·6	—	1·0
189·0	5·1	4·6	6·0
198·0	6·9	7·6	7·0
207·0	11·8	12·0	12·5
211·5	17·1	17·1	13·0
216·0	26·2	26·2	21·0
220·5	42·4	42·8	46·0
225·0	67·2	67·6	68·0
229·5	91·7	91·0	89·0
234·0	98·4	99·0	98·2
238·5	90·5	89·4	91·0
243·0	81·7	81·0	86·0
247·5	76·9	74·5	75·0
252·0	76·7	76·8	74·0
261·0	85·9	85·2	83·0
270·0	96·2	96·0	96·5
279·0	93·7	94·0	95·0
288·0	85·8	87·0	87·0
297·0	84·5	85·1	87·5
306·0	90·6	90·7	92·5
315·0	96·1	95·8	93·0
324·0	94·0	93·7	93·5
333·0	89·0	88·2	91·0
342·0	88·5	88·4	93·5
351·0	92·8	93·0	95·0
360·0	95·7	95·4	95·5

The time taken to work one result was about 5 min the computer and about 13 min with the Smith Char measure of the reproducibility of the results given b computer was obtained by repeating the calculation fo point $\theta = 225\cdot0$ which lies on the steepest part of the t mission curve. The result obtained from twelve succ computations was 68·00% with a standard deviation of

The systematic error revealed by this series of computa was attributed to some lost motion in the clutch mecha together with a possible maladjustment of the asse There is no doubt that a redesigned model made to limits would give improved results. However, the ge layout, as described here, appears to be quite sound. I computer were scaled up by, say, 30%, there woul course, be a disproportionate gain in accuracy sinc "play" in the pivots would remain as before.

NOTES ON THE CONSTRUCTION OF THE COMPUTER

The spiral was drawn on Bristol Board which previously been stuck to an aluminium disk: "4 sheet" B Board was stuck to the top surface with Araldite 10 Aero Research Ltd.) and the centre point then pr through. To draw the spiral values of the radius v $20/(1 + R/Z_0)$ expressed in centimetres were plotted ag $100 \log (100R/Z_0)$ expressed in degrees for values of ranging from 0·02 to 100, increasing in the clockwise s

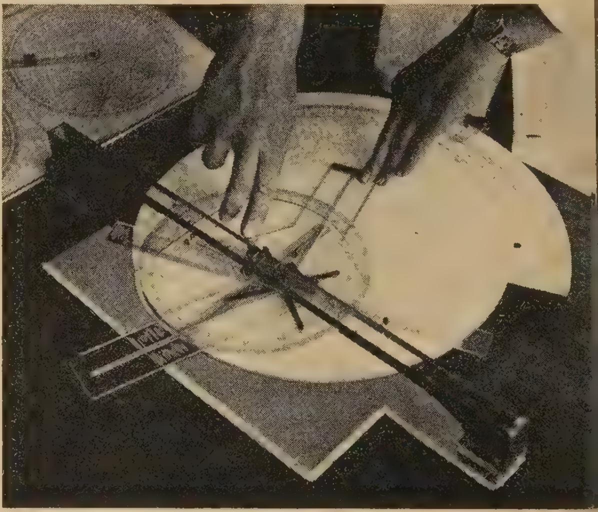

Fig. 5. Photograph of computer in use

The multiplication scale was drawn on the arc of a circ 23 cm radius. A number n on the scale was at an ang separation of $100 \log n$ degrees from the central datum ($n = 1\cdot0$), the sense of the scale being such that n incre in the anti-clockwise direction. Both drawings were tected with Morane plastic skin (by Morane Plastics Co. L The transmission scale was engraved on the upper ce of the arm C. The spacing of the scale was such that graduation line corresponding to a transmission $T\%$ at a distance $\sqrt{(100 - T)}$ cm from the central datum A photograph of the computer is shown in Fig. 5.

ACKNOWLEDGEMENT

e author wishes to thank the Director and Council of the British Scientific Instrument Research Association for permission to publish this article.

REFERENCES

(1) Smith, P. H. *Electronics*, p. 29 (January 1939).
(2) Smith, P. H. *Electronics*, p. 130 (January 1944).
(3) Leurgans, P. J. *J. Opt. Soc. Amer.*, **41**, p. 714 (1951).

An electrically-driven disk atomizer for high speeds of rotation

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Disk speeds ranging from 15 000–90 000 rev/min are attained by employing a variable speed d.c. motor/inductor alternator set and supplying the high-frequency output to a special induction motor carrying the disk. The apparatus is designed for continuous use at any speed and several protective devices permit unattended operation. The speed is measured by employing a diametral hole in the high-speed shaft to admit a light beam intermittently to a photocell. The resulting signal is amplified and fed to a standard frequency meter. Disk diameters are 2, 3, 4 and 5 cm.

spinning disk atomizer has been the subject of several rimental researches. There have been two methods of ng the disk; the use of compressed air, which forms driving fluid and support bearing, and the electric motor. e former method is only suitable for high-speed disks nall diameter and examples of its use may be found in work of Walton and Prewett(1) and of May.(2) Larger s have been electrically driven (Boshoff,(3) Friedman, ckert and Marshall,(4) Pattison and Aldridge(5) and rs).

The disk atomizer described below was constructed for the ultimate purpose of providing a spray of uniform droplets for injection into steam to assist condensation studies. It is, however, eminently suitable for liquid atomization studies and has been adapted for an interim research in this subject.

In view of its ultimate use the employment of air as a driving agency was deemed inadmissible, as the exhaust air would emerge from beneath the disk to mix with the steam, and it would also make a vertical axis of rotation imperative. Since in its final form the high-speed shaft will be horizontal

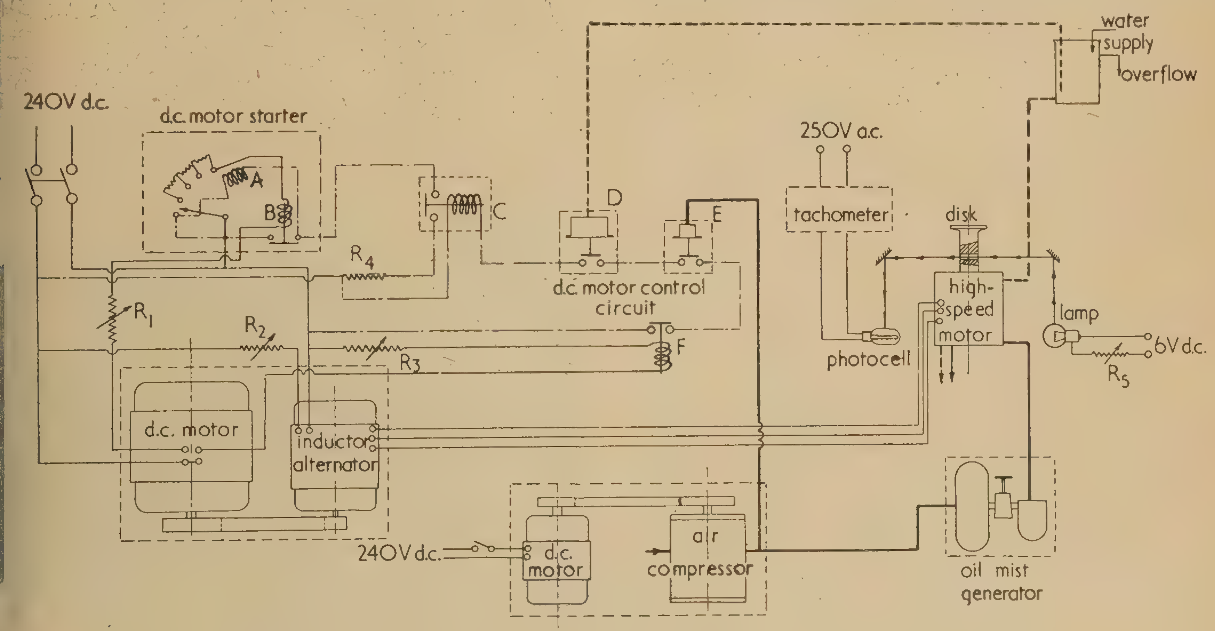

Fig. 1. Diagram of atomizing apparatus showing principal circuits

R_1 = 200 Ω, 240 W d.c. motor armature regulator.
R_2 = 250 Ω, 560 W inductor alternator field regulator.
R_3 = 1500 Ω, 375 W d.c. motor field regulator.
R_4 = 1500 Ω, 30 W motor starter resistance.
R_5 = 100 Ω, 25 W light source control.
A = d.c. motor starter; under-voltage release.
B = d.c. motor starter; over-current release.
C = mercury relay switch.
D = stator cooling water pressure trip switch.
E = oil mist pressure trip switch.
F = d.c. motor field relay switch.
—·—·— = d.c. motor control circuit.
------ = stator cooling water.
———— = air and oil mist.

and the liquid fed through the disk itself, an electric drive was preferred.

The paper describes the instrument itself and some no-load characteristics are given: atomization studies will be presented at a later stage.

GENERAL DESCRIPTION OF APPARATUS

The principal features of the apparatus are shown on the circuit diagram, Fig. 1. To attain the high speeds of rotation necessary on a small disk for fine atomization, a special high-speed induction motor is employed. This induction motor, built by Mollart Ltd., has a simple rotor with no windings and carries the disk directly on the shaft. The motor develops about ½ h.p. and is supplied with high-frequency three-phase a.c. from an inductor alternator set having a single fabricated bedplate. The complete unit is manufactured by British Thomson-Houston Ltd.

Variation of speed at the disk is accomplished by varying the speed of the d.c. driving motor. The normal speed of this is 1150 rev/min, reducible using armature regulation to 600 rev/min. Field regulation enables a maximum speed of 3500 rev/min. The corresponding extreme speeds and frequencies of the inductor alternator are respectively 1065/6200 rev/min and 300/1750 c/s. The corresponding synchronous speeds for the high-speed motor are 15 400/90 000 rev/min. Water supplied from a constant head tank to the high-speed motor stator enables the physical size of the motor to be kept to a minimum.

Lubrication for the high-speed motor ball bearings is in the form of an oil mist. Air at a pressure of 40 lb/in.^{2} is supplied by a motor-blower set, seen at the back of the general photograph, Fig. 4, at the rate of about 2 ft^3 of free air per minute. A ½ h.p. d.c. motor drives this eccentric vane-type blower through a single V-belt. The compressed air is passed through an inertia-type oil separator and reducing valve to a mist generator. The mist supplied to the motor bearings is at about 10 lb/in.^{2} and contains oil globules of approximately 2 μ. The special light oil employed is Mobiloil Velocite. The air also serves to keep the bearings cool and, by raising the interior pressure of the motor, prevents the ingress to the bearings of dirt and the liquid under test. The complete mist-generating set is manufactured by C. A. Norgen.

As the apparatus was designed to operate unattended for lengthy periods, certain protective devices were deemed desirable. To protect the high-speed motor from bursting, a Londex electrical trip relay *F*, Fig. 1, is provided, its coil being in series with the d.c. motor field. In the event of the field current falling below 0·12 A, the value associated with maximum speed, the control circuit is interrupted. The high-speed motor is also protected against failure of the oil mist or the stator coolant. The pressure switch *E*, Fig. 1, keeps the d.c. motor control circuit closed only while air pressure is maintained and the pressure switch *D* caters thus for the coolant. The set cannot be started up unless these two services are operating, or with a weak d.c. motor field.

The rotational speed of the high-speed shaft is measured by admitting a beam of light through a hole in the high-speed shaft. The light from a 6 V, 3 W lamp is turned through a right angle by a plane mirror. The beam passes then through a ⅛ in. diameter hole in the spindle and is again turned through a right angle by a second mirror before admission to the photocell. This arrangement of mirrors enables the light source and photocell to be removed from the proximity of the disk and makes space available at the top of the motor for a large liquid-catching tray. The hole in the spindl
jig-drilled and had to be placed with great accuracy.
output signal from the photocell is amplified and fed
frequency meter, type 726, made by Airmec Ltd.
employs a first-grade frequency-indicating meter which

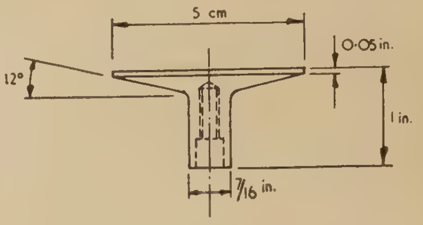

Fig. 2. Duralumin disk

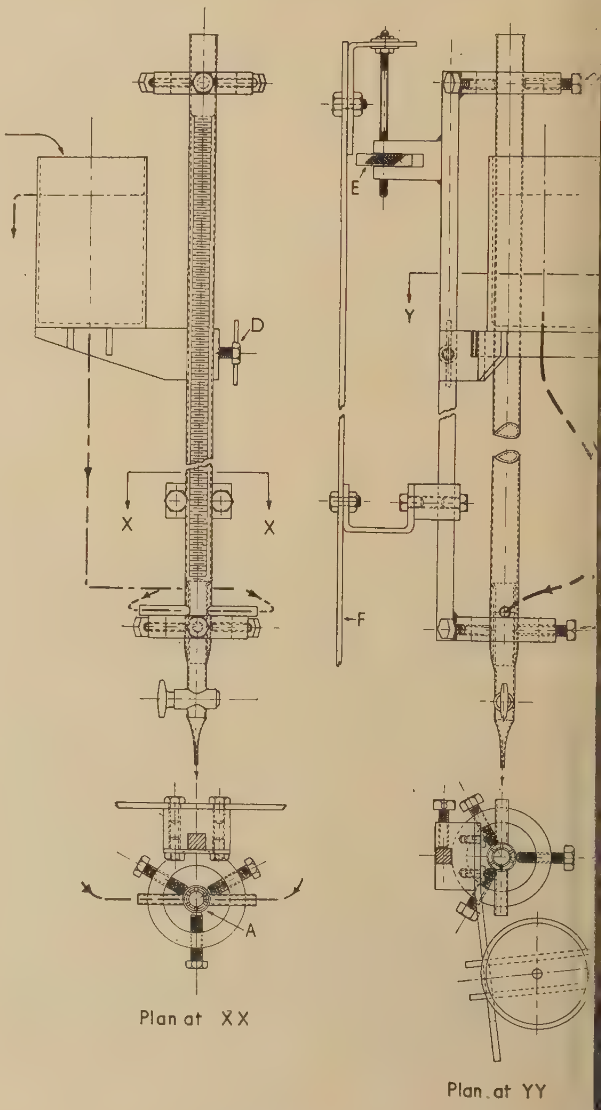

Fig. 3. Adjustable constant head reservoir assembly : supplying test liquid

A, copper sleeve for suppression of eddies at liquid ent
B, lower screws for verticality adjustment; *C*, upper scre
for verticality adjustment; *D*, adjustment for height of consta
head tank; *E*, vertical adjustment of complete assemb
F, main supporting frame.

— ––––– = liquid supply pipes.

rror of less than ±1% of the full-scale reading. The ment incorporates an oscillator circuit which operates frequency of 20 kc/s for self-calibration purposes. The ated speed is twice the actual spindle speed as the hole ts the light beam twice every revolution.

designing the disk, notice had to be taken of the fact it forms an overhung load, and since the apparatus is ded to be used at any speed from 20–100 000 rev/min, important that the first critical speed of the high-speed assembly should be avoided throughout this range. necessitated the use of a very light metal for the disk. also of paramount importance that the disk material ld be homogeneous to avoid unbalanced forces and of gth sufficient to withstand the stresses due to rotation. disks have been produced similar to that shown in 2, of sizes 2, 3, 4 and 5 cm diameter respectively. The d 3 cm diameter disks were both turned from 99·99% aluminium 1 in. diameter extruded bar. In the latter the bar was forged hot to obtain the necessary increase iameter. The 4 and 5 cm disks were turned from lumin bar which, while 4% heavier than aluminium, a greatly enhanced strength. The disk profiles were lated from considerations of uniform strength, for h the disk thickness t is given by

$$t = t_0 \exp\left[(-w\omega^2 r^2)/2gf\right] \qquad (1)$$

e t_0 is the thickness when the radius r is zero, w is the rial density, ω the rotational speed and f the allowable s. For the 2, 3 and 4 cm disks, f was 2 t/in.^{2} at 00 rev/min. In order to obtain a reasonable profile he 5 cm disk, it was necessary to accept a stress of .^{2} at 100 000 rev/min.

uation (1) gives a profile which is a shallow exponential e. To avoid the difficulty of machining such a profile a ble conical profile which was a near match was accepted. disk is fixed quite simply to the rotating shaft by a v so handed that the liquid load tends to screw the disk er on.

e arrangements for the supply to test liquid are shown g. 3. The liquid is supplied from an adjustable constant tank. On entering the burette it is introduced at two opposite points into an annular space between the glass and a hollow internal sleeve, the function of which arrangement is to destroy any horizontal velocity components in the

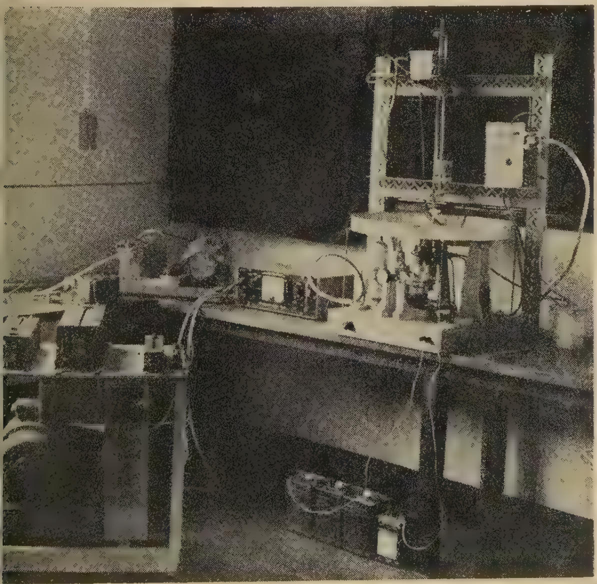

Fig. 4. Complete apparatus assembled for use

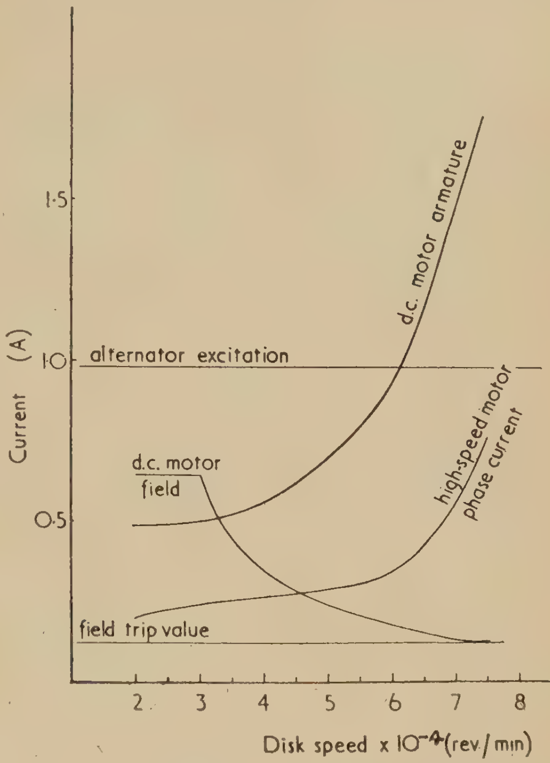

Fig. 5. No load current characteristics of atomizer
3 cm disk, no test liquid. Alternator field current equals 20% of maximum value

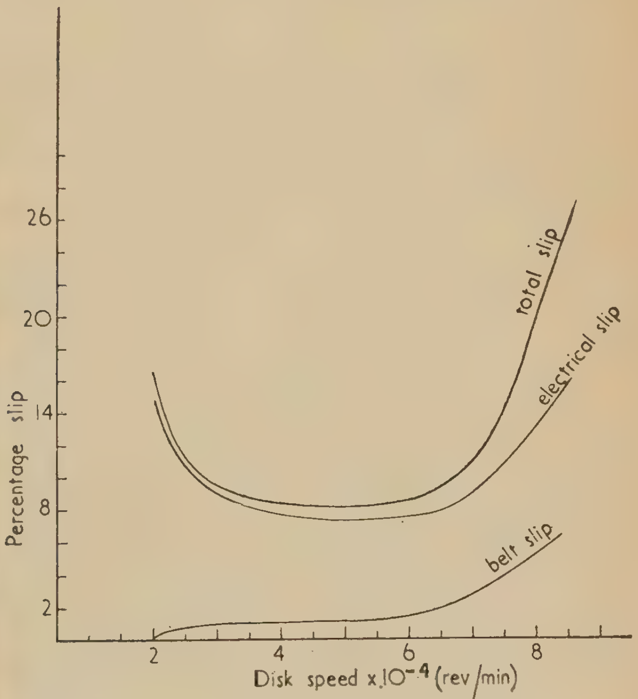

Fig. 6. No load characteristics of atomizer
3 cm disk, no test liquid. Alternator field current equals 20% of maximum value.

entering liquid. The burette is adjustable for verticality and for height and its carriage also supports the adjustable constant head reservoir of test liquid. With this arrangement, the space between the lower tip of the burette and the disk can be adjusted without variation of the liquid head and thus the flow rate. The three equally-spaced screws in the upper and lower retaining rings enable the burette exit tip to be alined over the centre of the disk. In such a position the burette can be lifted vertically without disturbing any adjustment by an amount sufficient to enable the disk to be changed.

It will be seen from the photograph, Fig. 4, that the apparatus is constructed as five separate and easily detachable units, i.e. the low-speed unit comprising a trolley carrying the motor-alternator set and control gear; the high-speed motor, tray and mist-generating unit; the motor-blower set; the Dexion bridge assembly carrying the coolant and test liquid reservoirs and supporting the burette; and finally the frequency meter.

OPERATION

Early difficulties were encountered with the tachometry. At the highest speeds the amount of light passing through the rotating shaft for each registration position is extremely small, and the frequency meter tended to become uncertain in action or to indicate a stable but ficticiously low value of speed. The difficulty was overcome by careful adjustment of the optical system, by increasing the filament brightness, by shielding the photocell from stray light and by employing a high amplification of the signal. To prolong the life of the photocell and light source, a dimmer was used with the latter and the filament brightness was increased until its value was just sufficient to promote steady indication of speed at the particular speed value chosen.

Some representative characteristic curves for no-load operation was shown in Figs. 5 and 6. For the slip curves, the slip is here defined for a connected rotary pair as

$$\frac{\text{No-slip speed of driven member} - \text{Actual speed of driven member}}{\text{No-slip speed of driven member}}$$

The "electrical" slip between the alternator and the speed motor can be reduced by increasing the alter excitation, but the slip at high speeds between the dr motor and alternator can only be reduced by increasing belt tension to an undesirably high value.

The complete unit has proved very satisfactory and s in operation at all speeds up to about 85 000 rev/min, and shown no tendency to hunt or fluctuate in speed with s changes in d.c. mains voltage. At the highest speeds it proved noisy owing to small residual unbalance in the which it has proved impossible to eliminate. A conical seating would probably be an improvement.

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REFERENCES

(1) WALTON, W. H., and PREWETT, W. C. *Proc. Phys.* (*London*) *B*, **62**, p. 341 (1949).
(2) MAY, K. R. *J. Appl. Phys.*, **20**, p. 932 (1949).
(3) BOSHOFF, W. H. *Proc. Instn Mech. Engrs*, **166**, (1952).
(4) FRIEDMAN, S. J., GLUCKERT, F. A., and MARSHALL, W *Chem. Eng. Proc.*, **48**, p. 181 (1952).
(5) PATTISON, J. R., and ALDRIDGE, J. D. *Engineer*, p. 514 (1957).

An improved electromagnetic integrator

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An electromagnetic integrator designed for use with an instrument providing automatic measurement of natural evaporation is described. The integrator can integrate an electric signal of varying polarity and operates satisfactorily for currents down to 5 μA, and for electromotive forces down to 0·6 mV according to the type of coil used. The latter is wound on a light damping frame to ensure accurate integration together with rugged performance. As zero drift cannot occur with this type of integrator, it could be applied to problems for which long periods of integration are required, such as daily totals of net vertical solar radiation.

Various studies in the field of meteorology have revealed the need for an instrument to integrate a rapidly varying electrical signal over a long period. In particular, such an instrument was required in connexion with equipment being developed to provide automatic measurement of natural evaporation. An integrator of the type suggested by Gilbert* appeared to be suitable in that there is no zero-drift and hence integration could proceed for an unlimited time. An additional advantage is that the energy required for operation is very small, so that in many cases the signal from a meteorological instrument could be integrated directly.

The integrating mechanism consists of a perma magnet moving-coil system similar to that used for indicating instruments, but without a spring restoring f It is readily shown that the total angular movement o coil is an accurate measure of the required integral. A pointer, attached to the coil, can engage contacts at ends of the range of coil movement, and, by means associated circuit, the polarity of the signal applied t coil is reversed when such contact is made. At the time the progress of integration is recorded on a me register.

The Gilbert instrument, however, has the severe limit that it can only integrate a signal of constant polarity.

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* GILBERT, R. W. *Rev. Sci. Instrum.*, **18**, p. 328 (1947).

nodification it cannot therefore be used in investigations as those met in the study of atmospheric turbulence, measurement of natural evaporation being a particular ple), where the signal to be integrated is usually of ing polarity. This limitation in the design has now been ved, and a description of the improved instrument is nted below.

DESIGN OF INTEGRATING MECHANISM

e equation of motion for a permanent magnet moving system, in which there is no restoring force, can be en in the form

$$\alpha(d^2\phi/dt^2) + \beta(d\phi/dt) = i \qquad (1)$$

hence for a system at rest at $\phi = 0$, $t = 0$

$$\int_0^t i dt = \beta\phi_t + \alpha(d\phi/dt)_t \qquad (2)$$

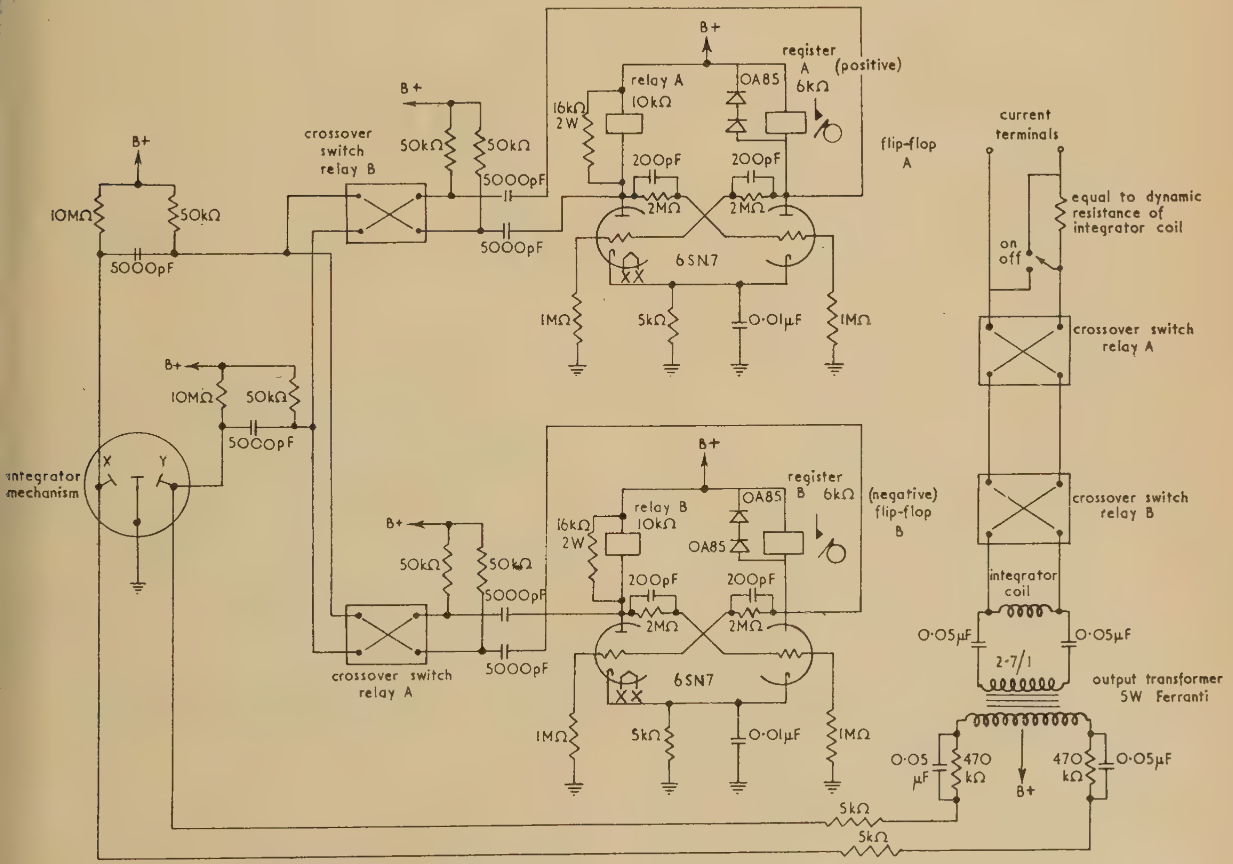
term $\beta\phi_t$ is then an accurate measure of the required ral if the term $\alpha(d\phi/dt)_t$ is small. In practice, this ires the response time α/β be sufficiently small, and this be achieved by providing heavy damping, either by the of a damping frame (in which case α must not increase ificantly), or, for a frameless coil, by relying on circuit ping. An alternative is to make the resistance external e coil equal to the source resistance when switching off, hich case the subsequent carry-over of the moving system lts in exact accounting of the term $\alpha(d\phi/dt)_t$.

more detailed analysis of the equations for both voltage current integration shows that there is no significant difference in performance between the possible damping methods. Frame damping was preferred in the present application, since the damping effect was present under all circumstances which might occur in the field, thus ensuring a rugged performance. A light aluminium frame was used, which provided sufficient damping and increased the moment of inertia of the moving system by only 30%. It should be noted that friction and air damping are not adverse factors if they are velocity proportional.

With the dimensions of the damping frame used in this case, the effective resistance of the coil when moving was approximately four times the static resistance and, for situations in which a low starting torque was necessary, the coil resistance was made equal to half the source resistance. This provided a satisfactory compromise between the conflicting requirements of low starting torque and maximum sensitivity.

In construction, the integrator coil was carefully balanced, and supported by hardened-steel pivots. The damping frame was made by cold working a section of thin aluminium tube. To ensure a reasonably constant damping effect over a batch of damping frames, all frames were constructed from the same piece of tubing using the same technique. Care was taken to avoid cracks occurring which would have seriously affected the performance of the integrator by reducing the damping.

Electrical connexions were made to the coil and the moving pointer by nickel wire (diameter 0·0005 in.) from a point immediately above the pivots in order to minimize torsional effects. For very low resistance coils (5 Ω), copper wire of the same diameter was preferred.



B+
register
A (positive)
6kΩ
relay A
10kΩ
OA85
16kΩ
2W
200pF
200pF
2MΩ
2MΩ
6SN7
XX
1MΩ
5kΩ
0·01μF
1MΩ
flip-flop
A
crossover
switch
relay B
50kΩ
50kΩ
5000pF
5000pF
10MΩ
50kΩ
5000pF
10MΩ
50kΩ
5000pF
integrator
mechanism
X
Y
register
B 6kΩ
(negative)
flip-flop
B
relay B
10kΩ
OA85
OA85
16kΩ
2W
200pF
200pF
2MΩ
2MΩ
6SN7
XX
50kΩ
50kΩ
5000pF
5000pF
crossover switch
relay A
1MΩ
5kΩ
0·01μF
1MΩ
current
terminals
equal to dynamic
resistance of
integrator coil
on
off
crossover switch
relay A
crossover switch
relay B
integrator
coil
0·05μF
0·05μF
2·7/1
output transformer
5W Ferranti
0·05
μF
470
kΩ
470
kΩ
0·05μF
B+
5kΩ
5kΩ

Fig. 1. Complete circuit of integrator

CIRCUIT DESIGN

The basic component of the associated circuit is a triode flip-flop arrangement. A relay, which can reverse the current to the integrating coil is used as the plate load of one triode and a message register is included in the plate circuit of the other to record the progress of integration.

The contact made by the pointer at each end of the range of coil movement can be used to trigger the flip-flop in a variety of ways, one of the most convenient being to produce a negative pulse and inject it into one plate of the flip-flop. A similar pulse from the opposite contact can be fed to the other plate.

The state of the flip-flop determines the polarity of the signal fed to the integrating coil, and, therefore, since the circuit cannot be triggered by a negative pulse at the plate of the conducting valve, the arrangement will operate only for a current of one particular polarity. By using a second flip-flop to deal with the opposite polarity, this property can be used to provide integration of a current having either sign. The circuit arrangement is shown in Fig. 1.

Flip-flop *A* operates relay *A* and the positive register, and flip-flop *B* operates relay *B* and the negative register. The current to the integrator coil can be reversed by either one of the relay-operated crossover switches placed in series in the current line. It will be noted also that if relay *A* changes over it reverses the pulse triggering connexions to flip-flop *B*, and *vice versa*.

Suppose initially that contact *X* can trigger flip-flop *A* and *Y* can trigger flip-flop *B*, i.e. *X* represents positive integration and *Y* represents negative integration, and suppose further that an *X* contact is made.

The sequence of events is as follows:

(1) flip-flop *A* is triggered, a positive count is recorded and relay *A* changes over;

(2) the change-over of relay *A*, reverses the current to the integrating coil, and reverses also the pulse-triggering connexions to flip-flop *B*;

(3) the new state of flip-flop *A* can now be triggered only by contact *Y* (relay *B* having remained unchanged), and flip-flop *B* can now be triggered only by contact *X* (by virtue of relay *A* having changed over).

A similar sequence will occur when any subsequent contact is made, with the appropriate message register operating according to whether the integration is proceeding positively or negatively. The initial requirement that one contact can only trigger one flip-flop and the other contact the other flip-flop is easily arranged by using identical wiring for each circuit for the pulse inputs from contacts through the cross-over switches to the plates of the valves, except at any one point where the wiring must be reversed. The circuit will then operate in the desired manner for any combination of the conducting states which may occur. It is not necessary therefore, to provide controls to pre-set the state of the flip-flops either when switching on or at any later stage.

The complete circuit is shown in Fig. 1. An unregulated 300 V *B* + supply is used, and no interaction occurs between the various units operating from a common supply. The trigger pulses are about 500 μs long; these are made small compared with the change-over time of the relay (several tens of milliseconds) to avoid incorrect triggering.

Gilbert fed a pulse from the plate of one of the valves to the integrator coil to prevent contact sticking at low speeds. This could not be done with the present circuit since the direction of the pulse would have been ambiguous, and so a separate pulse was obtained from the contacts and fed
transformer to the integrating coil to avoid this ambigui

As might be expected, the pulse size required depends
on the integrator coil resistance, and any resistance v
occurs in parallel with it; thus appropriate adjustme
the values of the components in this pulse generating c
may be necessary.

Normal 3000 type relays were used which operated w
current of about 3 mA. The circuit values were so arra
that the "on" current was 15 mA and the "off" cu
0·1 mA. A powerful return spring could then be fitte
the relays to provide a relatively fast release action,
avoiding sluggish operation due to a finite "off" current
residual magnetic effects. At the same time a firm switc
on action was retained.

PERFORMANCE TESTS

A typical calibration curve for the integrator is sho
Fig. 2. The electronic circuitry provides only a swit
action, so that the accuracy does not depend in any wa
valve characteristics.

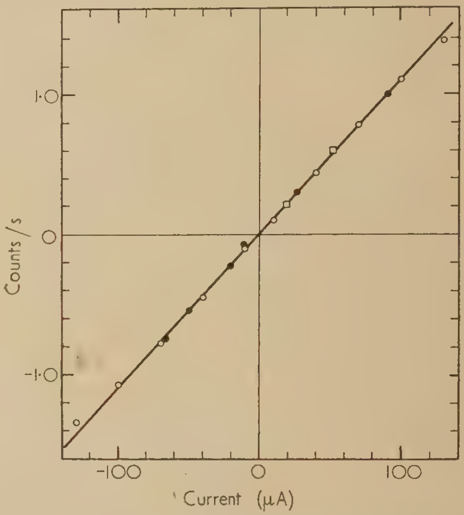


Fig. 2. Typical calibration curve for integrator
○ = d.c. only. ● = d.c. ± 30 μA a.c. □ = d.c. ± 60 μA

It will be seen that accurate integration was achieved
for cases where current fluctuations were several times
mean level. The accuracy of integration in all cases inv
gated in the frequency range d.c. to 10 c/s was better than

Two standard types of coil are used. One having a
tance of 500 Ω is intended for current integration and ope
satisfactorily for currents down to 5 μA; the other h
resistance of 5 Ω and can be driven directly by a M
Gorczynski Solarimeter for output voltages as low as 0·6
For the latter case, this means that daily value of integr
solar radiation can be obtained with an error of less than
owing to a finite starting current. A much simpler ci
can be used in this application, since the current t
integrated is of a constant polarity.

ACKNOWLEDGEMENTS

Thanks are due to Mr. R. R. McGregor for assista
and Mr. G. Harris for his careful construction of the
grating mechanism. Miss Y. Mullins carried out the ci
wiring on a number of instruments.

A compact and versatile fraction collector

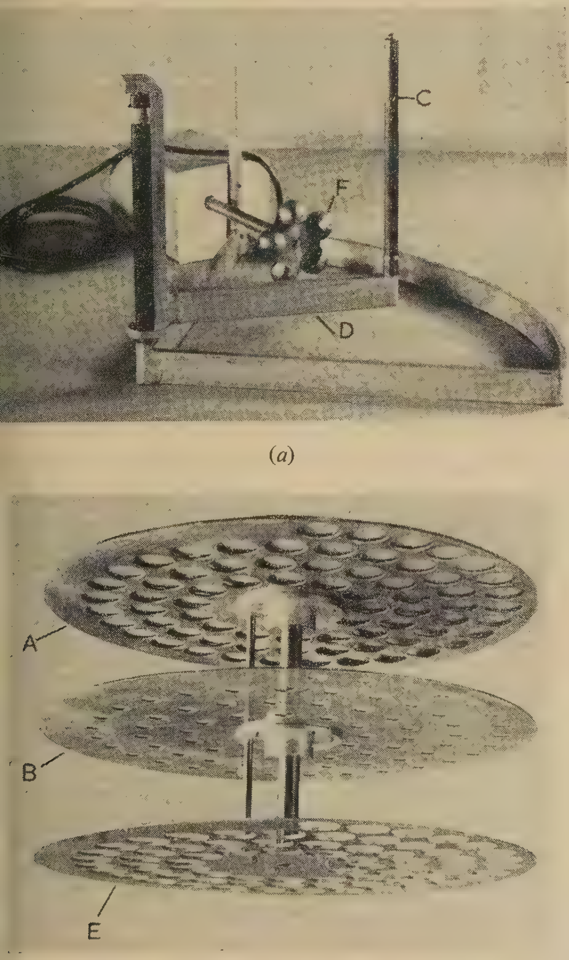
By A. Snow, F. A. E. Porter and A. W. Tomalin, Low Temperature Station for Research in Biochemistry and Biophysics, University of Cambridge, and Department of Scientific and Industrial Research, Cambridge

[*Paper received* 4 *November*, 1957]

A versatile fraction collector is described, which has many desirable features. The tubes are arranged spirally to conserve space, but each tube is brought in turn directly under the column in order to avoid mixing of successive drops in any connecting tube. The turn-table movement can be initiated without difficulty by most devices used for determining sample size. The turn-table itself is easily replaceable and can be removed and used for storage.

y chromatographic fraction changers are described in literature and include types operated by siphons, float es, weighing devices, time intervals, etc. The consequent of standardization and interchangeability is a great dvantage where a number of fraction changers are in use ne laboratory.

ne collector described here was designed to be versatile regard to the size and number of the receivers and to the nod of determining the size of fraction and is operated by nall electric motor. Collectors with receivers placed in a le ring on a turn-table are unnecessarily large. The size he turn-table can be greatly reduced by arranging the ivers on a spiral of close pitch, but this complicates the problem of transferring the liquid from the tip of the column to the appropriate receiver. In the present apparatus this has been solved by a simple and automatic movement of the turn-table, which brings each receiver in turn under the column and thus avoids any mixing of successive drops. Further advantages of this collector are that it is relatively silent in operation, the turn-table is simple to construct, and it can be removed for use as a storage rack or reset to any point on the spiral. For many purposes the volume of the fraction may be controlled sufficiently accurately by the number of drops in it, although most of the usual methods of determining sample size, e.g. siphons, clocks, proximity switches, etc., can be arranged to start the motor.



(*a*)

(*b*)

Fig. 1 (*a*) and (*b*). Photographs of collector with turn-table removed

In the fraction collector described the fall of the drop is detected by either a photo-electric method or by a simple mechanical switch. The detector output drives a counter using cold cathode decade tubes that is both silent and flexible. When the pre-determined count is reached the control relay operates, the turn-table brings the next tube into position and the counter is reset to zero.

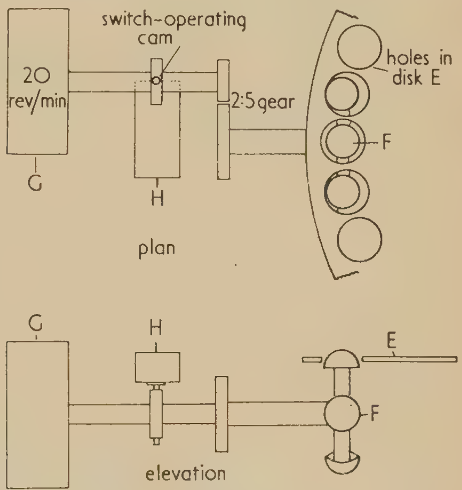
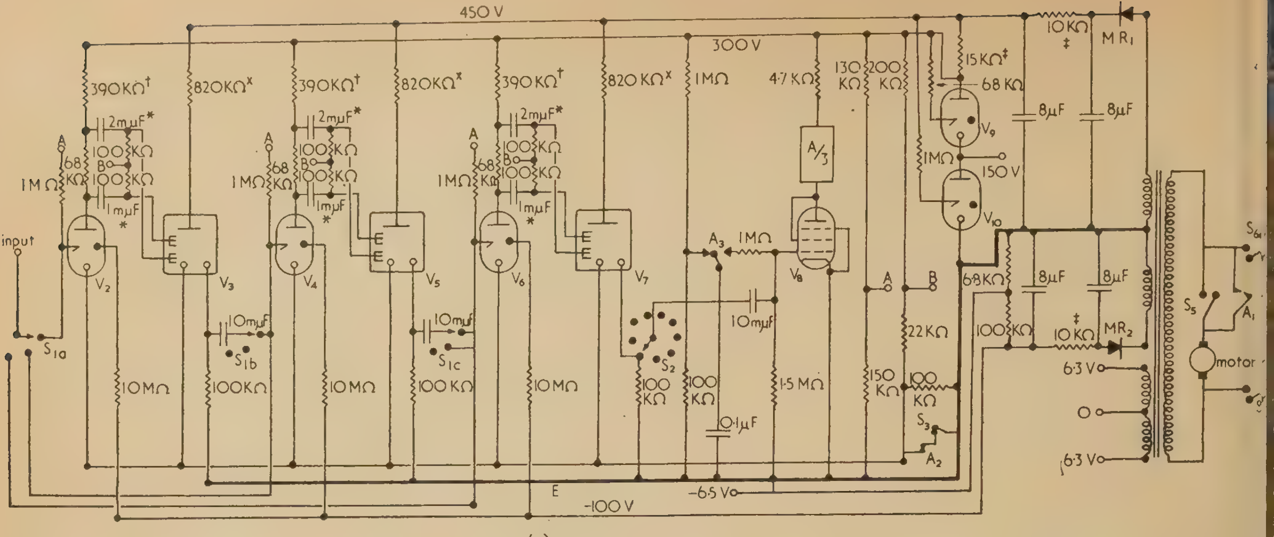
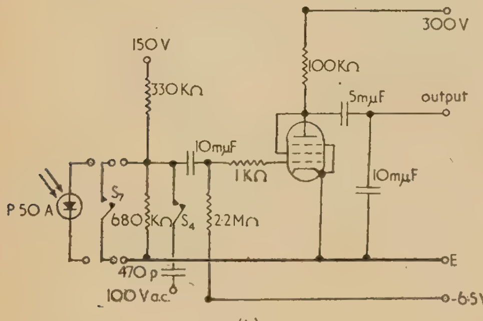


Fig. 2. Drawing showing layout of turn-table driving mechanism

Fraction collector (*Figs.* 1 *and* 2). Test-tubes are used and are normally hung by their rims in holes arranged on a spiral of close pitch in a sheet metal disk *A*. Where space is vital rimless tubes may be used and supported at their lower ends by a disk *B*. The disk *A* rotates on a vertical spindle *C* which is mounted on a swinging arm *D*; thus all tubes may be brought in sequence under the fixed fluid outlet. It is positioned by an identical disk *E* fastened to the same central component, the pattern of holes coinciding. This lowest disk is moved by a small wheel *F* with five equally-spaced projections on its periphery. These projections enter the holes



(a)



(b)

Fig. 3. Circuit of drop-counter (*a*) and associated input units (*b*)

V_1 = EF91
V_2 = GTE175M
V_3 = GS10C
V_4 = GTE175M
V_5 = GS10C
V_6 = GTE175M
V_7 = GS10C
V_8 = EF91
V_9, V_{10} = GTR150M/S

Relay $A/3$ = P.O. type 3000, 5 kΩ coil, 1 pair "make," 1 pair "break," 1 pair C/O

MR_1 = half-wave, 500 V, 100 mA
MR_2 = half-wave, 125 V, 25 mA
S_1 = multiplier switch, 3-pole, 3-way
S_2 = units selector
S_3 = manual reset zero (open to zero)
S_4 = 50 c/s test
S_5 = micro switch on turn-table
S_6 = mains on-off
S_7 = switch on mechanical unit
All resistors ¼ W ± 10% except: ‡ 5 W, † high stab, × adjust for I_k = 320 μA
* tolerance ±5%

from below and, like an elementary pinion and crown wheel, turn both disks, one hole at a time.

The motive power is provided by a small electric motor *G* which drives the wheel *F* through a 2 : 5 gear. It is started by the output relay of the drop counter and stops itself after placing an empty tube in position, i.e. after the driving shaft has completed half of a turn in about 1½ s, by operating the microswitch *H* which is wired in parallel with the contacts on the output relay. It will be appreciated that the output relay must remain energized until the cam has cleared the microswitch.

Photo-electric unit. The drop of effluent falls through the beam of light which is focused on to a germanium junction photocell. When the drop interrupts the light the photocell produces a voltage pulse which, after suitable amplification, is passed to the counter. The sensitivity of the amplifier is adjusted so that the counter will operate reliably on the normal drop while minute secondary drops cannot give a sufficiently large output pulse to operate the counter.

Simple mechanical unit. This unit forms an alternative to the photo-electric unit when the solution is light-sensitive. A beam of stainless steel wire with a drop collecting loop at one end is pivoted in the centre and counter-poised at the other end. The loop is placed just touching the tip of the column and gradually fills with liquid. When the weight is sufficient to overcome the counterpoise, the beam tips, and the drop falls into the tube. The wire then returns to its original position. An electrical impulse is produced by platinum switch contacts S_7 [Fig. 3(*b*)] fastened to the beam between the loop and the pivot.

The counter (*Fig.* 3). The basic requirement of the cou was that it should count reliably and silently a wide rang impulses. A commercial batching counter could have used, but the circuit of a simpler counter which has a lim but adequate range of drop numbers is shown in Fig The counter uses Dekatron "selector" tubes in all sta these have separate connexions to each cathode, so tha selecting the appropriate cathode it is possible to determine the number of drops passing before the ou relay is energized.

In the circuit shown, the output selector is precede either 1 or 2 stages each multiplying the selected num by a factor of 10. Thus by setting the switches S_1 and it is possible to count in units from 1 to 9, in tens from to 90 and in hundreds from 100 to 900. The multipl stages are easily modified to multiply by factors of 2 using 10-way tubes or by 2, 3, 4 or 6 using 12-way select In this way the drop number can be chosen from a range. Several fraction collectors using turn-tables opera on the principles described here, but with different meth of determining sample size, are in use in this laboratory have proved satisfactory in operation over a period several years.

This fraction collector is the subject of British provisi patent number 12545/57 administered by the Nati Research Development Corporation. The work descri in this paper was carried out as part of the programm the Food Investigation of the Department of Scientific Industrial Research.

A high voltage electron injector gun for synchrotrons*

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An improved demountable electron injector gun designed primarily for use in 140 and 30 MeV synchrotrons is described. The maximum energy of injection is 100 keV: facilities for the exploration of synchrotron injection parameters are provided by micrometer control of both the radius and the injection angle of the beam. Both the cathode assembly and the anode are easily detachable for replacement and experimental purposes. Details of the gun design, its electrical characteristics, and the test apparatus are given.

s established(1) early in the operation of electron syn- rons that higher X-ray output from the machines was ly obtained if the energy of the injected beam was ased. To obtain maximum output at the higher ion energy it was also necessary to increase the injection current. An optimum radial distance of injection was d, which varied with the alinement of the accelerating ber and other parameters, and for each radial setting timum injection direction was obtained.

the earlier electron injector guns used in the 30 MeV rotrons designed at Harwell,(2,3) the injection radius adjusted by four screw-threads equispaced on a flange d the circumference of a bellows. These adjustments allowed some variation of injection angle to be obtained pping the whole gun structure. Further variation of njection angle was possible by the application of a bias ge to one half of the split anode. However, difficulties experienced with vacuum leaks in the bellows and a precise method of adjustment was required for variation jection angle and radius.

ese earlier guns had a tungsten filament and operated injection voltage of 30–40 kV. Since the filaments had erate under conditions that were not ideal, their lives short and they consequently had to be replaced at ent intervals. A filament assembly was therefore ired that could be easily replaced.

e final design of gun described here is capable of ating with injection voltages of up to 100 kV. Micro- r type adjustments vary the radial position of the gun and can move the cathode relative to the anode, thus ging the field distribution between the two electrodes, therefore varying the beam injection angle. Bellows been excluded from the design, the movement asso- d with the micrometer adjustments being taken through g seals. Both the filament assembly and the anode are ly detachable.

GENERAL DESCRIPTION

ce the gun is held between the betatron flux return bars e synchrotron, it is subject to a 50 c/s alternating mag- field with a value at the cathode of 10^4 oersteds(3) g to 2×10^3 oersteds at the main vacuum seal on the This intense field naturally limits the choice of rials to be used in the injector gun.

e gun shown in Fig. 1 basically consists of a central lar cylinder, on which the cathode is mounted, sur- ded by a second circular cylinder supporting the anode n in Fig. 2. The latter cylinder is at earth potential, is supported in guides in the metal section of the gun envelope, whilst the central cylinder, at high negative potential, is supported in copper bearings sealed to the glass part of the envelope. Both cylinders can be independently moved a maximum axial distance of 2 cm by their respective micrometers. A non-magnetic stainless steel is chosen for the cylinders, since a material with low eddy-current loss, low hysteresis loss and a high resistance to electrical breakdown is required. The concentric cylinder construction ensures that the probability of dielectric breakdown in vacuum is minimized. With an adequate insulation path between the two electrodes, electrical breakdown is normally confined to the regions where symmetry fails, i.e. in the cathode-anode area.

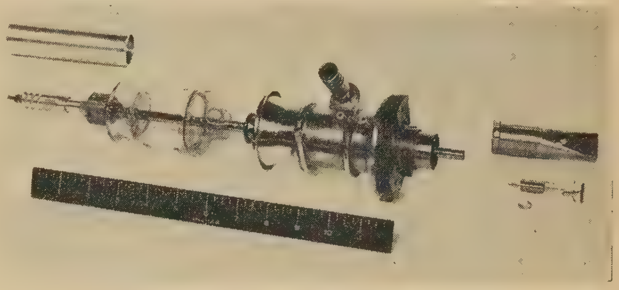

Fig. 1. Injector gun

The anode is made of molybdenum, as are also the filament supports and the filament shield.

The main body of the gun is also located in the fringing field, and thus eddy-current losses are high; in addition the ambient temperature of the betatron flux return bars is about 40° C. Water cooling is therefore necessary to prevent an excessive rise in temperature and failure of the O-ring seals. As the body is not subject to electron bombardment it is machined from brass, with a copper feather-edge glass-to-metal seal soft soldered to one end.

The vacuum seals between the gun and the orbit tube and between the stainless steel cylinders and their respective micrometers are neoprene O-rings located in machined grooves.

The cathode micrometer and corona shield are supported on a small feather-edge seal at the back of the gun, and to reduce the weight supported by this seal the cathode micrometer was specially machined from Duralumin. For convenience, the cathode and anode micrometers are arranged to give the same axial movement of the electrodes with the same direction and degree of rotation. In order to achieve this the anode micrometer is specially machined with a left-hand thread, and drives the anode support tube through a double rack and pinion (Fig. 3). Backlash in the micrometer

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* G.E.C. communication No. 769.

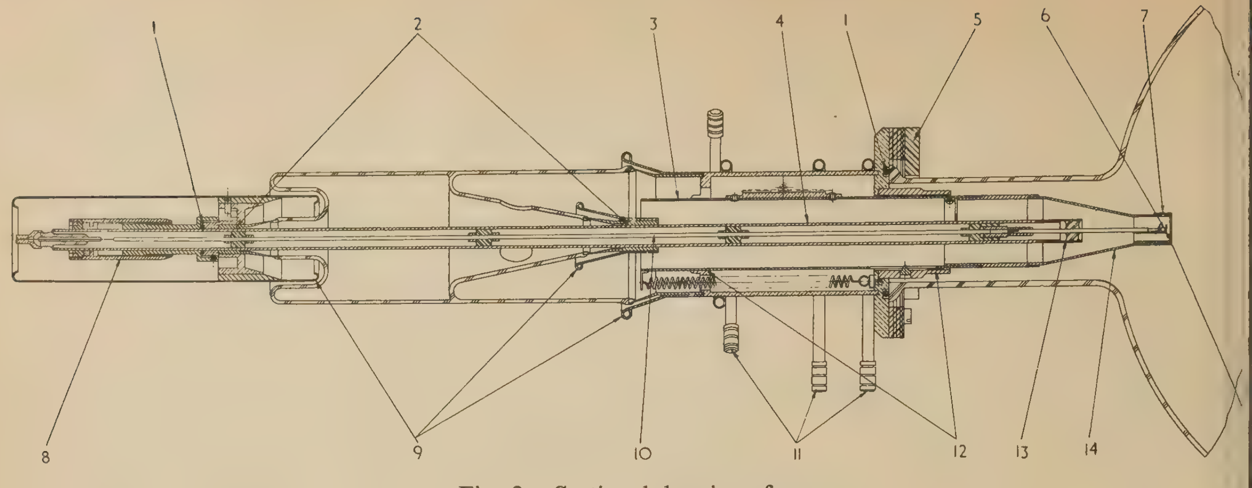

Fig. 2. Sectional drawing of gun

(1) Neoprene O-rings; (2) cathode cylinder guides; (3) anode cylinder; (4) cathode cylinder; (5) clamps; (6) filament. (7) grid; (8) cathode micrometer; (9) corona shields; (10) heater lead; (11) water-cooling tubes; (12) anode cylinde guides; (13) cathode assembly; (14) anode; (15) filament shield.

drive is minimized by externally threaded locking rings at the end of each micrometer thimble, while backlash in the rack and pinion is overcome by three beryllium copper springs between the anode cylinder and gun case. Thus the injection radius can be determined from the anode micrometer reading, while the difference between this reading and that of the cathode micrometer may be interpreted in of the beam injection angle.

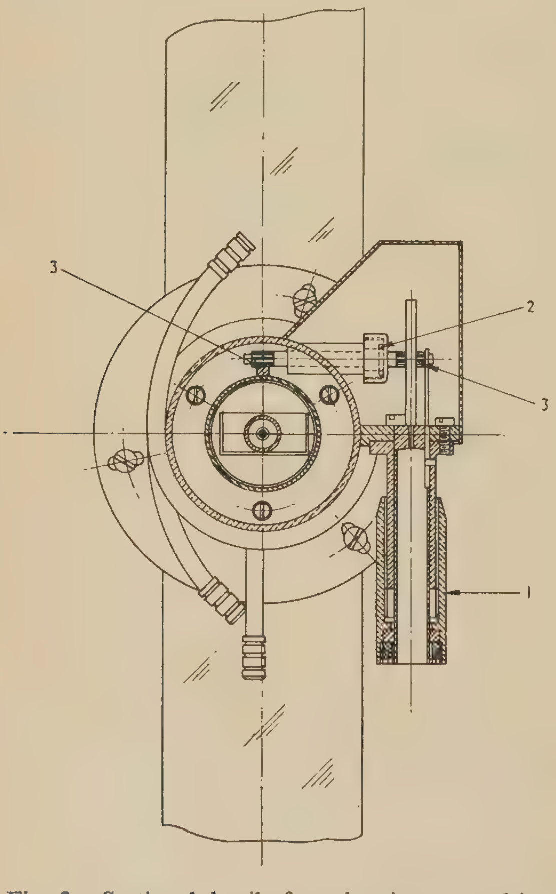

Fig. 3. Sectional detail of anode micrometer drive

(1) Anode micrometer; (2) neoprene O-ring; (3) rack and pinion drive.

The heater connexion is located axially in the ca cylinder, on to which the completed filament assemb designed to slide, being located axially and circumferen by a spring clip. The anode is also readily detachabl is located by a sprung pin integral with this sub-assemb

ELECTRODE DESIGN

As the gun is mounted with its main axis at right a to the tangent of the stable orbits, the gap between the of the filament coil and the innermost part of the a must be as small as possible, otherwise the injected elec will impinge on the back of the anode after completing first revolution in the orbit chamber. A value of 2· has been chosen for this distance and is adequate.

An electrolytic tank(4) was used to determine the ele trajectories and the gun equipotentials. It was found 16% of the potential difference between anode cathode penetrated beyond the anode slit. This field tration was considered excessive, as it would have distu the circulating electrons in the orbit, and was reduced t by the addition of a molybdenum grid (50 wires/in.) a the gap with the axis of the wires (0·1 mm diameter) pe dicular to the axis of the filament coil. Measurements in both the electrolytic tank and the test gear show decrease in beam divergence with the use of the grid.

Initially the guns were made with tungsten filaments as injection voltages were increased, higher beam cur were required to allow optimum output. The avai heater supply rating was such that a change was ma carburized thoriated tungsten filaments to obtain the req emission. Beam currents of 500 mA are obtained at a ment rating of 20 W, while currents of 1A have been obt for short periods, governed by the rapid loss of the ca surface. These filaments consist of twenty-one turns 0·4 mm diameter mandrel of 0·3 mm diameter wire, an arc-welded to their molybdenum supports before carburized.

Two types of filament assembly are made for the the standard filament assembly has a rectangular fila shield and gives a fairly divergent beam, while the altern ıbly has a lipped filament shield, the lips forming ce"(5) type zero potential focusing plates. This modi- on of the standard design resulted in a reduction of ximately one third in the included beam angle in the at right angles to the filament axis. Using these lipped ent shields the maximum gun voltage is reduced to t 80 kV, since a more intense electrostatic field is pro- l at the edge of the lip. However, since the available ge from the users pulse unit is in the range 60–80 kV, limitation of performance is not serious. With the w beam assemblies an improvement has been noted in rotron output for the same injected current in a MeV machine. No similar improvement has been noted 30 MeV, 10 cm radius machine.

would be difficult to effect a further reduction in beam in the present gun, with its basic restriction on the ıce between the anode and cathode structure, which in limits the width of the focusing electrode.

HIGH VOLTAGE OPERATION

the gun is demountable, and O-rings are present, it is aked during initial evacuation. It has therefore to be ge-aged slowly, since during this process, the pressure ble to rise suddenly and an arc develop which may ture the glass envelope. At the most vulnerable places, e feather-edge seals, corona rings are provided.

tially, under test conditions, the filament is switched on vacuum of 5×10^{-6} mm of mercury or better. The e voltage is increased slowly over some hours up to V until the gun will run steadily without breakdowns of er frequency than one per two minutes in the anode- de region. With the modified shape of filament shield, aximum voltage attained is about 80 kV. Attempts to ve the rate of ageing by electropolishing the stressed ces resulted in very little gain. A fully-aged cathode ture has a surface similar to that which has been sub- l to shotblasting. The mechanism of this breakdown using the marking is similar to the "flash arc"(6) effect l in high power transmitting valves.

ce a gun is aged to a given voltage, subsequent re- g up to the same voltage takes only a short time. How- further slow ageing is necessary to exceed the first

periments have shown that with the simpler design of ent shield, a 1·5 mm gap is adequate to support a ge difference of 100 kV (5 μs pulse) between the bdenum surfaces. With smaller clearances, field gths of 2 MV/cm at 60 kV have been noted, with only nittent breakdowns.

TEST APPARATUS

e tests on the gun are carried out in an evacuated glass ber in which the pressure is monitored by both Pirani onization gauge units. The chamber is evacuated by a ury vapour pump through a liquid air trap and cut-off g a theoretical pumping speed of 6 l/s at the gun. It ound that this speed was sufficient to keep the pressure v 10^{-5} mm of mercury during the voltage-ageing of the nd consequent gas evolution.

e gun is inserted into the chamber and the vacuum g seal made in a similar manner to that used between and the orbit tube. When this seal is made the gun , and its main axis is parallel to, a Willemite fluorescent screen which is ruled in centimetre squares to enable measurements to be made on the beam position and angle relative to the gun axis.

During test the cathode assembly is pulsed negatively with respect to the anode by a pulse equipment similar to that used in operation.(3) The 5 μs pulse is fed from a delay line to a 1 : 10 pulse transformer. This transformer has a bifilar winding for the gun filament supply. Using this system, voltages of 120 kV have been attained. Since a dangerous amount of X-radiation is produced by the gun during voltage-ageing, the vacuum chamber is enclosed in a $\frac{1}{16}$ in. thick lead box with lead glass viewing panels. These precautions reduce the radiation outside the box to well below tolerance levels.

A copper mesh screen is placed over the interior surface of the test chamber, since it was found that without it distortion of the beam occurred due to the surface of the glass becoming negatively charged.

OPERATIONAL EXPERIENCE

In use the gun has shown a marked improvement over earlier types since injection radius and angle are simply adjusted with the gun in position, and the micrometers give close control and good repeatability of the above parameters. Under the various vacuum conditions encountered, the life of the thoriated tungsten filaments has varied between a few hours and several hundreds of hours. However, with interchangeability of filament assemblies, replacement of this component takes only a few minutes. Experience with the narrow beam filament assemblies has shown that a given synchrotron output has been obtained in the 140 MeV machine at the Clarendon Laboratory, Oxford, with a very much lower injected beam current than that required from a wide beam assembly.

Little information is available on the operational voltage performance of the gun at over 80 kV between the electrodes, but it would appear, as might be expected, that under vibratory conditions the maximum peak voltage the gun will support is lower than that obtained under static test conditions.

Typical injection conditions are; a total filament emission of 500 mA at 60 kV with an injected beam current of 400 mA giving a through gun efficiency of about 80%.

ACKNOWLEDGEMENT

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REFERENCES

(1) Elder, F. R., Gurewitsch, A. M., Langmuir, R. V., and Pollock, H. C. *J. Appl. Phys.*, **18**, p. 810 (1947).

(2) Goward, F. K., Lawson, J. D., Wilkins, J. J., and Carruthers, R. *Proc. Instn Elect. Engrs*, (I), **97**, p. 320 (1950).

(3) Fry, D. W., Dain, J., Watson, H. H. H., and Payne, H. E. *Proc. Instn Elect. Engrs* (I), **97**, p. 305 (1950).

(4) Baker, B. O. *Brit. J. Appl. Phys.*, **5**, p. 191 (1954).

(5) Pierce, J. R. *J. Appl. Phys.*, **11**, p. 548 (1940).

(6) Gossling, B. S. *Proc. Instn Elect. Engrs*, **71**, p. 460 (1932).

A spectrograph attachment for high speed cameras

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An attachment is described which will convert any camera into a spectrograph. Used with two typical high-speed cameras, time resolved spectrography of small sources is possible with a wavelength resolution of 3 Å at 5780 Å and resolution times down to less than 10^{-7} s. With a third camera, spectra of phenomena having a spatial dimension may be recorded at rates up to $1 \cdot 6 \times 10^6$ frames per second.

INTRODUCTION

High-speed cameras of divers kinds are considerably and widely used in investigations into the mechanisms of fast events. In this laboratory they have been used particularly for examining the processes of the burning, deflagration and explosion of unstable materials,(1) and the emission of light from electric discharges.(2) It can be desirable on occasion to use spectrographic techniques to extend knowledge of these events, generally,(3) though not universally,(4) restricting examination of the event to a single spatial or a single time dimension.

Unless there is justification for the construction of a special spectrograph to suit a particular task, it seems preferable to devise an attachment which may be added to a variety of cameras. This not only enables each spectrographic technique to be exploited in turn by varying the type of camera, but simplifies procedure where it is desired to take ordinary and spectrally dispersed pictures of the same experimental event,(4) without substitution of one camera for another. Such an attachment is realized below, after discussion of the compromises that must be effected to suit it to several types of camera, and to work over a long range of wavelengths. Time resolved spectrography is not limited to studies of emission spectra. To extend the use of the attachment to studies of the absorption spectra of explosives during burning and detonation, such events must be illuminated from behind by sources of high intensity. With a view to their use for this purpose, the variations with time of the spectral emission of some electric discharges have been examined.

CAMERA TYPES

In this laboratory we have three "film on drum" cameras working up to writing speeds of 16, 30 and 100 m/s, image stabilization and rotating mirror framing cameras up to 3000 and 1 600 000 frames/second respectively, as well as versatile image converter cameras, several types of image splitting and image dissection cameras, and numerous still and movie cameras of slower speeds. With a few exceptions these cameras use ordinary photographic lenses of the usual range of field angles, and of fairly large relative apertures. For spectrographic work these cameras may be grouped according to the field angles over which adequate resolution is maintained.

Typical of those of normal field angles (about 30°) are the 16 and 100 m/s drum cameras. These are fitted with 7 in. $f/2 \cdot 5$ Aero Ektar (Eastman Kodak) and 2 in. $f/2$ Sonnar (Zeiss) lenses respectively. When viewing the same event, the difference in writing speeds should make it possible to "iris" the Aero Ektar lens down to about $f/5 \cdot 6$, while maintaining about the same silver density on the same type of emu
as with the Sonnar lens in the faster camera at full ape
Hence the effective diametral aperture of both lenses ca
taken as about 30 mm.

The image converter equipment has a 24 mm dia
circular photocathode, and is therefore often fitted
lenses designed for 35 mm film cameras. The Zeiss Sc
lenses of 50 mm focal length ($f/1 \cdot 5$) and 85 mm focal le
($f/2$) have apertures of 35 and 42 mm respectively and op
over a narrow range of field angles (11 to 16°) when im
a line 17 mm long on to the photocathode.

Cameras of very narrow field angles may be repres
by the Beckman and Whitley 189 framing camera whic
a lens of 24 in. focal length. The image width on the rot
mirror may be an inch, or an inch and a quarter; bu
use of 35 mm film for recording restricts the useful p
to 24 mm; hence the field angle is less than $2\frac{1}{2}$°.

The resolution of any of these cameras in use is us
limited by the film to little more than 500 black and
line pairs across the field.

THE DISPERSING ELEMENT

There is a fairly clear choice to be made between gr
and prism devices for dispersing the light accepted by
attachment. A single high index prism (Chance D
801255) or two of lower index (Chance LF 579411) pro
about the same dispersion (12–15°) in the 3500 Å to 55
region as does a 30 000 line/in. grating working in the
order. 90° deviation systems, convenient for constru
and experimental apparatus, may be designed around e
with about the same facility. The glass will naturally ab
a considerable fraction of the light in the 3500 Å to 40
region, which would be reflected by a grating; however,
of this is lost in any case in the multi-element camera le
and by diffraction into unwanted orders.

Marginal advantages in favour of the grating are tho
cost, where an aluminized replica grating is likely t
cheaper than a prism of the same aperture and si
resolving power; and of uniformity of dispersion,
shows but little variation for a grating between the en
the visible spectrum, but a difference of about a fact
two for a prism.

The grating normally suffers the disadvantage of prod
overlapping orders of spectra, though this will rarely co
the skilled spectrographer. This provision of several o
is a considerable advantage where cameras of divers
angles are in use. Thus the first order spectrum may be
to cover the field of a narrow angle camera, while a ca
of normal angle can accommodate the second order spec
from the same grating. Any overlap can sometime
turned to advantage, since superimposing wavelengths
different orders bear simple numerical ratios to each oth

Cameras of very narrow field angles will require a ely pitched grating if any great range of wavelengths is recorded at one time. Hence a 30 000 line/in. grating d not be a particularly good choice for a versatile hment. A suitable compromise may be one of about 0 to 15 000 lines/in., the second order visible spectrum hich fits a lens of about 14° field angle fairly well. In to resolve about 500 lines across a 2000 Å field a length resolution of about 4 Å is required. A grating ly 1500 ruled lines would theorectically satisfy this rement at wavelengths up to 6000 Å. Hence the mini- ruled length, the pitch having been determined from the mentioned considerations, would appear to be about n. However, physically it will need to be 3 to 4 in. in h, in order to use the whole of the apertures of the able camera lenses, when tilted at an angle. The width ling (length of ruled lines) need only be about 35 to m.

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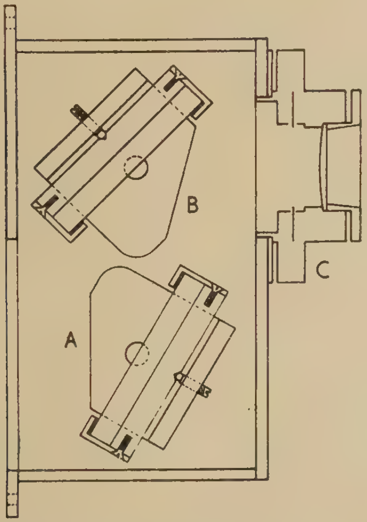
* Now at the Vickers Group Research Establishment Weybridge.

THE COLLIMATOR

multipurpose collimating system seemed possible for arge range of scale involved in different types of experi- . However, the simple arrangements necessary, a pair ossed adjustable slits and a collimating lens, may be nbled afresh from components suited to each experiment urn. Either spherical or cylindrical systems may be red, depending upon whether the camera lens be sed at infinity, or at the collimator slits. The former ngement is to be preferred, as spherical collimator lets, adequately corrected for chromatic and spherical ations, are readily obtainable. Where a high per- ance is not required of the system, ordinary spectacle s may be pressed into service in this capacity.

gain, an aperture of about 40 mm is adequate to the rest e system, and it is convenient to provide a mount for s of about this size, on the casing of the spectrograph hment, together with a capping shutter.



g. 1. A section through the optic axes of the spectro- aph attachment. The grating *A* and plane mirror *B* e rotatable about axes normal to the drawing, and ay be given small amounts of tilt for "squaring on" adjustment of the supporting screws, two of which are own. The capping shutter *C*, attached to the front of e casing, carries a mount for collimator lenses, one of which is shown in position

THE COMPLETE ATTACHMENT

A functional drawing of the device in section is shown in Fig. 1, and its actual appearance in the photograph of Fig. 2. It can be seen that a removable plane mirror of surface aluminized, selected plate glass has been added. This optionally straightens out the optical system, producing a 4 in. displacement between entrance and exit optic axes.

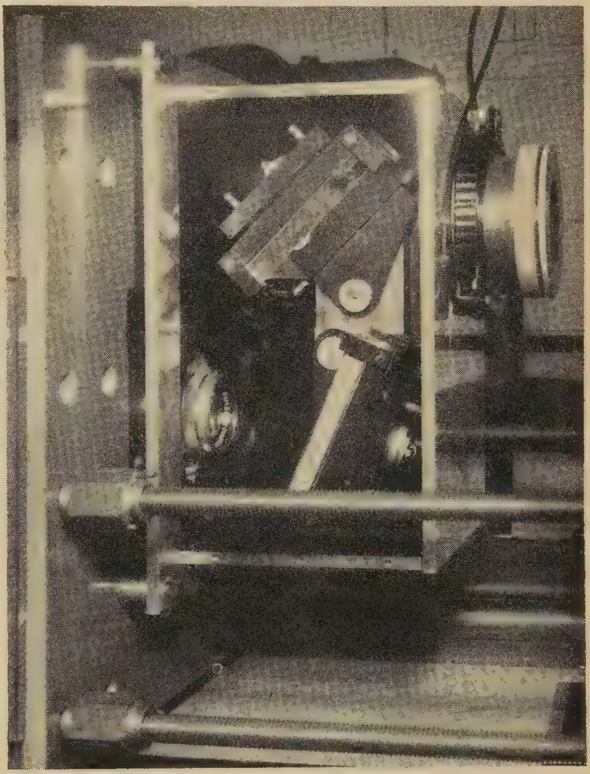


Fig. 2. The spectrograph attachment, screwed to the lens panel of the image converter equipment. Through a clearance hole in the rear panel of the casing, the 50 mm Sonnar lens of the camera focuses the diffracted light on to the photocathode of the image converter. In use, the near side of the casing is closed with a detachable panel. Provision of suitable screwed holes in the lens panel enables the attachment to be fitted horizontally, to provide a horizontal spectrum better suited to some varieties of camera

Both this mirror and the grating, a gelatin replica of a 14 400 lines/in. Blythswood ruling, are attached by three-point adjustable mountings to angle plates. These may be clamped to the casing, after rotating to aline entrance and exit axes with the collimating slit and camera system respectively.

The casing is fabricated from Duralumin sheet internally blackened, and may be bolted to a supporting framework or to the camera lensboards, being stood off where necessary by interposed washers. In Fig. 2 the lensboard is a 12 × 12 × ½ in. Tufnol sheet, drilled to fit a robust optical bench system evolved in the laboratory.(5) A no. IV Compound shutter has been fitted to the front of the casing, and carries a mount for collimator lenses.

SYSTEM PERFORMANCE

The grating attachment was set up with a 0·5 D spectacle lens collimating the light from a low pressure mercury discharge lamp. The source size was reduced to very small dimensions by reflection from a front aluminized convex mirror. The light diffracted by the grating was focused on to film on the periphery of the (stationary) drum of the 16 m/s drum camera, by means of the 7 in. Aero Ektar lens set to an aperture of $f/5{\cdot}6$. Under these conditions the second order yellow mercury lines 5790·65 Å and 5769·6 Å each appeared to be broadened by the aberrations of the system to a width of about 3 Å. This figure may therefore be accepted as the wavelength resolution of the system. Due to slight astigmatism the image patches were somewhat longer in the time direction. At a peripheral speed of 16 m/s their size would correspond to a time resolution of 85 μs. Second order green and yellow lines and third order violet and blue lines appeared all to share the same "best focus" position, suggesting a reasonable balance between the chromatic and the other aberrations of the system.

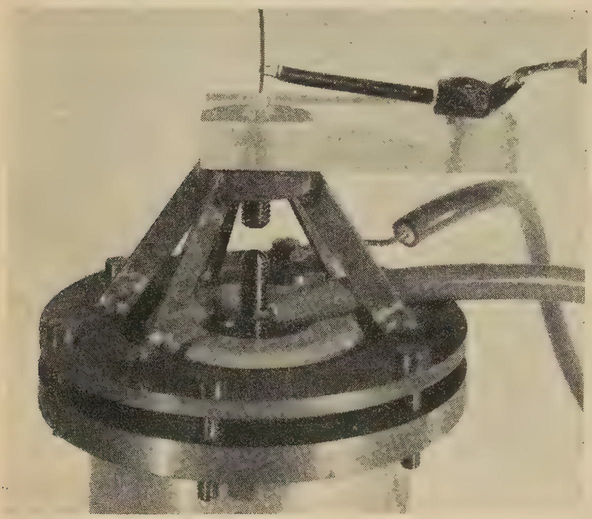


Fig. 3. The capacitor and discharge gap used experimentally to obtain figures for the time resolution of the spectrograph, when used in conjunction with an image converter equipment. The capacitor has been specially constructed to allow the attachment of an external discharge circuit of low inductance, of which that shown is a typical example; some further reduction of this parameter should be possible, by substitution for the "cage" shown of a solid pressing of suitable shape

The spectrograph attachment and collimator lens were then transferrred to the image converter camera, which had been fitted with the 50 mm Zeiss Sonnar $f/1{\cdot}5$ lens. This was opened to full aperture, and the undeflected image inspected at the fluorescent screen through a low power microscope. The image quality appeared to be limited by two defects. First there was a marked difference of camera focus for the yellow and the violet ends of the spectrum. This could be reduced to a negligible quantity by introducing some tilt into the alignment of camera lens and photocathode. Second, the outer zones of the system produced a noticeable amount of spherical aberration at the blue end of the spectrum, not confined to the centre of the field. Both defects improved rapidly as the camera lens was stopped to $f/2$. It was inferred, from the nature of these defects, the resolution of the system would fall rapidly with fa detail contrast in the subject.

However, no difficulty was experienced in separating mercury yellow lines, and a wavelength resolution of was estimated.

The time resolution of the image converter is relate the maximum sweep velocity at which the event is luminous enough to be recorded.(2) The system was t on a convenient subject of high luminosity, the disch channels of a high current spark in air and in argon. T discharges were located in a gap built coaxially on to end of a capacitor (Fig. 3), constructed specially for circuit inductance. To this end also the capacitor has fitted with a compact terminal insulator made to the aut design. In performance the unit is at least the equal of described previously,(6) and more convenient to use. some modifications to the "cage" forming the earthy re path, an even better performance should be possible.

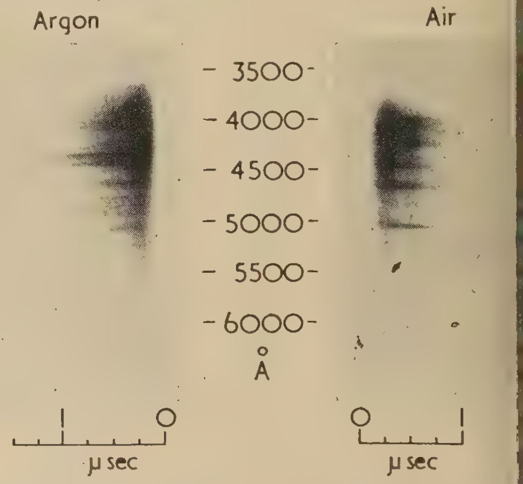


Fig. 4. Time resolved spectra of argon, and of a excited by the discharge of a 0·1 μF capacitor charg to 7 kV, using the image converter fitted with a 50 m $f/1{\cdot}5$ Sonnar lens as an image sweeping device. T fluorescent screen was photographed by means of Wray $f/1$ copying lens on to Ilford LN fast blue sensiti plates. It can be seen that for the first quarter micr second of the discharge (approximately the duration the first half-cycle of the discharge current wavefor the light is emitted as a bright continuum. This is su sequently displaced by a number of broad emission line which narrow as the discharge "cools." The emissi lines are typical of the gas excited by the discharge, b the continua appear to differ little. It may be deduc that the bright emission lines afford the greatest int grated intensities within narrow wavelength bands, b that where a lower light level may be tolerable sectio of the continuum may provide shorter "flashes Further analysis of a quantitative nature may obtained by examination of the negative record with microphotometer. The rapid cut-off of the system the near ultraviolet is well illustrated in these picture

Useful swept spectra (Fig. 4) of a 2 × 4 mm air s (Sonnar at $f/1{\cdot}5$) and a 2 × 8 mm argon spark (Sonna $f/2$) were obtained on Ilford LN fast blue sensitive pl using a Wray $f/1$ lens to photograph the fluorescent sc of the image converter tube. Calculation from the sys parameters (collimator focal length 133 cm, sweep spee cathode 5·6 mm/μs) gives values for the time resolution and 54 mμs. Both these figures are well within the l resolution limit for the system.

amination of the spectra shows strong continua lasting 0·2 to 0·25 μs, merging into broad emission line a, the lines of which narrow as the discharge "cools." be suggested that sections of the spectra containing no ed line emission could profitably be used for the ation of light pulses of very short duration.

continuum containing no line structure is especially l as an illuminant for studies of the absorption spectra tain events. Such events may themselves contain strong ion lines, in which case it is inadvisable to introduce from the illuminant source. Where continuum emission uired to last longer than the 0·2 μs or so of the above arges, a continuum duration of several microseconds be afforded by enclosure of the discharge in a quartz ary.(6)

POSSIBLE EXTENSIONS

ile it is possible to examine a wide range of events with paratus described above, some subjects are not possible, because the emission from them is too feeble to be ded, or alternatively because, as is the ultraviolet, the ion is selectively absorbed by the glass lenses.

int subjects may appropriately be dealt with by increasing perture of the camera lens. C. G. Wynne has suggested ate communication) the use of a Wray 64 mm $f/0{\cdot}7$ lens is purpose, as a version of this has been computed for ty/focal length conjugate working. This is more nable than the use of wide aperture catoptric systems, e latter inevitably occlude the centre of the system, ding an otherwise useful section of the grating. A ar lens, computed for near conjugates, might be employed e recording camera. In addition the grating may be d to throw a high proportion of the light into a selected . Faster recording emulsions are possible, up to ed speeds of 10000 A.S.A.(7) For special devices, such e image converter camera, improvements are possible e collection of light from the screen of the tube itself; the light guide devices suggested by Courtney-Pratt.(8) al of these suggested methods employed in combination ld raise the "aperture" of the system by a large factor. tension to working in the near ultraviolet (2000–4000 Å) nds entirely upon devising a suitable camera lens. Those monly employed in spectrographs and monochromators ashioned from quartz, and it is not readily possible to e a system of low aberrations and wide aperture, using material alone. Fluorite also transmits the ultraviolet, if expense is no object, may enable two component omats to be constructed. These might be designed as ats over a field of narrow angle, or as "landscape" s over wider fields. A field flattening lens may be added near the image plane; no attempt seems to have been to design a "Cooke triplet" lens from quartz and ite. Four component aplanats, for example the Lister oscope objective, might also be considered, as they ally afford numerical apertures up to 0·28 over small relatively curved fields.

general it may be simpler to allow the centre of the ng to be occluded, and, as Dyson has done,(9) design a mirror objective of wide aperture, with its residual rations corrected by means of thin quartz lenses.

should be noted, in the case of the image converter era, that the photocathode window must also be of quartz if the system is to accept the ultraviolet region. Further, for devices such as the Beckman and Whitley framing cameras, in addition to replacing the main objective lens, the whole of the relay lens system would need to be replaced by quartz optics. There is much, therefore, to be said for restricting the examination of the ultraviolet to simple camera systems, a typical fast example of which, Brixner's rotating mirror box camera,(10) may be cited.

Alternatively, visible light cameras may be modified to u.v. sensitivity, not by direct substitution of quartz optics, but by the addition of a u.v. to visible light conversion device. This may take the form of a simple image converter, of no more complexity that say the "Sniperscope," or be a u.v. sensitive phosphor. The primary image can be formed on this by any of the "lenses" considered above, and the visible image photographed by the camera. The spectrograph attachment may be added to the combination. This sort of solution lends itself also to exploration of the far ultraviolet region, i.e. wavelengths less than 2000 Å. Thus if the camera system must be outside the vacuum chamber in which such experiments are undertaken, a simple image conversion device might be used as the link between the grating inside and the camera outside the chamber.

Extension to the near infra-red, i.e. to a limit of about 12000 Å, is principally a matter of using photographic emulsions suitably sensitized for this region. This does not apply to image converter equipment, since the photographic record is of the visible emission from the fluorescent screen; instead, here it is the photocathode that must be sensitized to the infra-red. Discussion of recording methods for the far infra-red (1·2–20 μ) is not within the scope of this paper. The theoretical problems involved have been discussed by Fellgett.(11)

CONCLUSION

It has been shown that it is possible to construct an attachment which will convert any camera into a spectrograph. When designed to suit a variety of high-speed cameras, the device enables time resolved spectra to be recorded. In general, the wavelength resolution is restricted by the quality of the camera lenses to about 3 Å, where a 14400 lines/in. grating is used. On the fastest cameras, the time resolution is limited by the light collecting ability of the lenses to about 27 mμs. Suggestions are made for increasing the "aperture" of such systems, where shorter resolution times are required; the development of the device, described at length, has facilitated a swift appraisal of the emissive behaviour of some electric discharges of short duration.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of the following: Dr. L. A. Sayce of the National Physical Laboratory, for the manufacture and loan of a grating; members of Steatite and Porcelain Ltd., and of the WEGO Condenser Co. Ltd., for assisting in the construction of a special discharge capacitor; Dr. J. S. Courtney-Pratt for useful criticism of the MS. of this paper; and Dr. F. P. Bowden for his continued support.

REFERENCES

(1) Bowden, F. P., and Yoffe, A. *Initiation and Growth of Explosions in Liquids and Solids* (London: Cambridge University Press, 1952).

Bowden, F. P., and Yoffe, A. *Fast Reactions in Solids: Decomposition of Explosive Crystals.* In preparation.

(2) Courtney-Pratt, J. S. *Photogr. J.*, **92B**, p. 137 (1952).

(3) Gordon, G., and Cady, W. M. *J. Opt. Soc. Amer.*, **40**, p. 852 (1950).
Blitzer, L., and Cady, W. M. *J. Opt. Soc. Amer.*, **41**, p. 440 (1951).

(4) Zernow, L., and Hauver, G. E. *Proceedings of the Third International Congress on High Speed Photography*, p. 305 (London: Butterworths Scientific Publications, 1957).

(5) Courtney-Pratt, J. S. *Instrument Practice*, **11**, p. 959 (1957).

(6) Thackeray, D. P. C. *J. Sci. Instrum.* **35**, p.
(1958).

(7) Eastman Kodak. *Photogr. J.*, **97**, p. xi (April, 195

(8) Courtney-Pratt, J. S. U.K. Patent Applica
28407/56.

(9) Dyson, J. *J. Sci. Instrum.*, **32**, p. 272 (1955).

(10) Brixner, B. *Proceedings of the Third Internati*
Congress on High Speed Photography, p. 289 (Lon
Butterworths Scientific Publications, 1957).

(11) Fellgett, P. B. *Vistas in Astronomy* (Ed. A. B
1, p. 475 (London: Pergamon Press Ltd., 1955).

A simple, automatic, high-temperature thermal analysis apparatu

By S. J. Lloyd and J. R. Murray, M.A., Atomic Energy Research Establishment, Harwell, Berks.

[*Paper received* 13 *January*, 1958]

A simple, automatic, high-temperature, high-vacuum thermal analysis apparatus is described. The sample, in a chamber which may be evacuated to better than 10^{-5} mm of mercury at 1000° C, is heated by a molybdenum element and the thermal arrests are indicated by the differential method. By placing the sample in direct contact with the thermo-couple hot-junction, solid state phase changes may be detected in samples as small as 0·3 g. Alternatively, samples of 20–80 g may be contained in crucibles and, using the arrangement, thermal arrests have been detected at temperatures up to 1550° C.

A vacuum thermal analysis apparatus based on the differential method, in which the temperature of the experimental sample is measured and compared with that of a standard specimen by means of thermocouples, has been built for the examination of phase changes in metals and alloys in the temperature range 400–1550° C. The standard specimen should be of similar thermal capacity to the sample and should undergo no phase changes in the relevant temperature range. By amplifying the e.m.f. due to difference in temperature between sample and standard, increased sensitivity may be obtained over direct time/temperature measurements. The system lends itself to automatic recording, enabling the apparatus to run unattended. An earlier version of this equipment was described in an A.E.R.E. report.⁽¹⁾

SPECIMEN ASSEMBLY AND TEMPERATURE MEASUREMENT

Ideally, the experimental sample and reference block should be positioned in a region of zero thermal gradient in the furnace. For investigating solid state transformations in small samples (0·3–5·0 g), the sample and reference block are placed side-by-side (arrangement *A*, Fig. 1) and are supported by the platinum/platinum–13% rhodium thermocouple hot junctions. The thermocouple leads pass down a sillimanite support tube and out to a cold-junction at a vacuum- and water-tight plug which is at the temperature of melting ice. The specimen assembly is surrounded by a nickel or molybdenum shield of comparatively large thermal capacity.

For melting-point determinations in samples of 20–80 g, or the investigation of solid state arrests in samples which react with the thermocouples in the temperature range investigated, a crucible is used. The base of the crucible contains a sheath into which the hot junction of the sample thermocouple is inserted, the thermocouple leads pa
through a central hole in the reference block (arrangem
Fig. 1).

The e.m.f. produced by the sample thermocoup
recorded on a multi-range potentiometric recorder
5 mV full-scale deflexion and automatic switching bet
ranges; alternatively, spot readings may be made

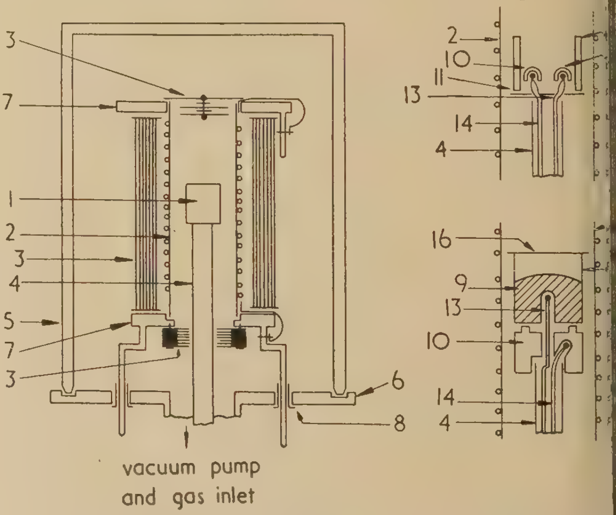


Fig. 1. Schematic arrangement of furnace chamber

(1) specimen assembly (see *A* and *B* for details); (2) furna
tube; (3) molybdenum radiation shields; (4) sillimani
support tube; (5), water-cooled stainless steel bell ja
(6) stainless steel base plate; (7) water-cooled rings; (8) pol
thene sleeve; (9) sample; (10) reference block; (11) ceram
disk; (12) nickel or molybdenum shield; (13) sample therm
couple; (14) comparison thermocouple; (15) crucibl
(16) crucible lid.

ually operated potentiometer. This thermocouple forms arm of the differential system, the second arm consisting identical thermocouple embedded in the reference block, connected in opposition to the first one at the cold junc- The resulting differential e.m.f. is amplified by a d.c. lifier and recorded beside the temperature/time trace on potentiometric recorder to indicate the occurrence and tion of a thermal arrest (Fig. 2). Reference blocks of ral sizes are available and one of similar thermal mass e particular sample is selected.

THE FURNACE

e heating element consists of a winding of molybdenum on a sillimanite tube 2 in. inner diameter and 6 in. long; s a power consumption of 1100 W at 1000° C and has used to detect phase changes at temperatures up to ° C. The ends of the furnace tube are a sliding fit in water-cooled rings, supported by thin stainless steel tubes h serve as both water and current leads.

e specimen assembly is supported by a sillimanite tube h is attached to the lower of the two rings by a lead-screw anism, by which its height may be varied from outside vacuum chamber (for clarity, the lead-screw mechanism been omitted from Fig. 1). The heating element is mally shielded on the outside by an assembly of six 5 in. thick molybdenum sheets fixed in annular grooves hined in heat resistant stainless steel end plates. The and bottom of the furnace are closed by a series of ybdenum radiation shields.

TEMPERATURE CONTROL

he power supplied to the furnace is controlled by two able rotary transformers connected in cascade; the first sformer pre-sets the maximum voltage applied to the ace, and the second modifies the voltage output of the from zero to the maximum. The second transformer is or driven through a variable gear-box, enabling heating cooling rates of 0·5 to 40° C/min to be obtained; stable limit switches determine the extent of the pro- nme and permit repeated scanning of the chosen perature range.

VACUUM SYSTEM

he furnace is surrounded by a continuously evacuated, r-jacketed, stainless steel bell jar seated upon a stainless base plate, the vacuum seal being made *via* a neoprene er ring. The vacuum inside this chamber is maintained rotary vane pump backing a 4 in. oil diffusion pump. rge stainless steel liquid nitrogen trap is mounted between diffusion pump and the furnace chamber, and a device rovided to maintain the correct liquid nitrogen level for ut thirty-six hours at a time. An ionization gauge is rted through an O-ring joint into the 4 in. pumping line below the base plate, which is water-cooled by external ing pipes welded beneath it. Stainless steel has been wherever possible for the permanent parts of the mbly, since excellent facilities exist in this laboratory for n-arc welding and electropolishing. This provides a em which is robust, leak-tight and possesses a surface h is easily cleaned and outgassed. The vacuum is tained at about 5×10^{-6} mm of mercury at 1000° C, does not appear to deteriorate significantly above this perature, provided the heating rate is kept below about 5° C/min. Provision is also made so that experiments may be performed in an inert atmosphere when necessary.

Since the apparatus normally runs unattended on automatic recording, safety interlocks have been fitted against failure of vacuum, water, liquid nitrogen or power supply.

EXPERIMENTAL

The apparatus has been in use in this laboratory for a number of years and has proved a versatile, reliable and convenient aid to alloy constitutional studies. Fig. 2 shows a typical thermal analysis result obtained with a 774 mg specimen of uranium using arrangement *A*. The transformation temperatures derived from it are given below:

Heating		*Cooling*	
Arrest	*Temperature (°C)*	*Arrest*	*Temperature (°C)*
$\alpha \rightarrow \beta$	675	$\beta \rightarrow \alpha$	658
$\beta \rightarrow \gamma$	780	$\gamma \rightarrow \beta$	774

The temperatures of the arrests on heating agree with those generally accepted for this material, but the hysteresis between the heating and cooling arrest temperatures is less than that observed with large specimens owing to recalescence. The cooling curve in Fig. 2 exhibits recalescence of about 15° C in both the $\gamma \rightarrow \beta$ and $\beta \rightarrow \alpha$ transformations. The differential deflexions become sharper with a decrease in specimen size, down to approximately 0·6 g; both these effects are due to negligible temperature gradients in the sample.

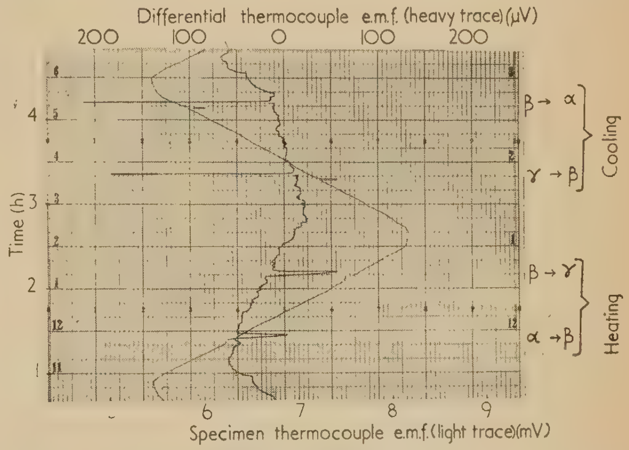


Fig. 2. Heating and cooling curves for 774 mg sample of uranium. Platinum/platinum–13% rhodium thermocouple. Heating rate 2·3° C/min. Differential thermocouple pen writes $\frac{1}{8}$ in. in front of specimen thermocouple pen on chart.

Thermal arrests have been readily detected in 0·3 g samples of uranium, but with samples of this weight the observed recalescence is only about 3° C, owing to the relatively high thermal mass of the thermocouple hot junctions and to the thermal conductivity of the thermocouple leads.[2,3] The last two effects govern the lower size of sample which may be used. Arrangement *A* (Fig. 1) is also preferred for the investigation of solid state transformations, since it is possible to use small homogenized samples which are suitable for direct dilatometric, X-ray and metallographic examination. Considerable economy of materials is thus achieved, which is important when using materials in short supply.

Neither the temperature nor the differential trace are completely stable, thus limiting the sensitivity of this type of apparatus. Random variations in the time/temperature trace are, for the most part, due to mains voltage fluctuations which have a relatively large effect on a system of small thermal capacity such as *A*. This effect has been reduced by stabilizing the mains input voltage, and by using a nickel or molybdenum tube as additional thermal capacity when small specimens are being studied. Differential fluctuations are contributed mainly by thermal gradient variations across the two sensitive elements of the system. Major causes of such gradient variations are (i) relative positions of the sample and reference block with respect to the isothermal region, which can be adjusted, and (ii) difference in thermal capacity between the two masses, which in many cases is tempera dependent.

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REFERENCES

(1) Lloyd, S. J., Murray, J. R., and Waldron, M. *A.E.R.E. Report M/R* 1461 (1954).

(2) Boersma, S. L. *J. Amer. Ceram. Soc.*, **38**, p. 281 (19

(3) de Josselin de Jong, G. *J. Amer. Ceram. Soc.*, p. 42 (1957).

A method of obtaining accurate relative pressures in the range 20 to 200 mm of mercury

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A refined visual method of accurately setting a mercury surface to a tungsten reference point is described in detail. The technique is applied in a differential manometer system to the establishment of a scale of relative pressures which is self-consistent to better than two parts in 100 000.

Because of refraction errors at the glass walls, the problem of sighting on the summit of a mercury meniscus and other difficulties, conventional mercury-in-glass manometers are not to be relied upon to give pressures to better than 0·01 mm of mercury. Whilst this error is not significant for many purposes, for work requiring the greatest attainable precision, and especially so at pressures below 200 mm, the percentage error is disappointingly large. This paper describes a technique of measuring relative pressures with an error not exceeding two parts in 100 000 on pressures as low as 20 mm. The principal feature of the apparatus is the use of a null manometer in which mercury surfaces are set to the same horizontal plane by being brought just into contact with tungsten points. The point setting can be made reproducible to about 0·000 2 mm and so is about fifty-fold more delicate than a cathetometer setting. The volume of a sample of reference gas is determined with high precision at a pressure which is known approximately. The sample of reference gas is expanded until, as indicated by the null manometer, its pressure equals that of a pressure of experimental interest, and the new volume of the reference gas is then determined precisely. Other experimental pressures are similarly treated. From the precisely determined volumes of the reference gas, the exact pressures relative to the initial assumed pressure are readily calculated by the ideal gas law. Though the absolute values of the computed pressures are limited by the precision of the single pressure determination of the initial pressure, the accuracy of the comparative pressures is limited only by the volume determinations and the exactness of the pressure equality condition. For many purposes these relative pressures suffice.

DESCRIPTION OF APPARATUS AND OPERATION

The main parts of the apparatus, Fig. 1, are enclosed in a large water bath which is maintained at a steady temperature within 0·02° C by thermostatic control. Two similar Pyrex glass dead spaces (*A* and *A*′) about 50 cm^3 capacity, c taining accurately-centred tungsten reference points, connected to a cylinder *B* of capacity 500 cm^3. The quant of mercury in the dead spaces and the cylinder can be adj within 0·2 cm^3 by means of vacuum and air pressure app to the mercury surfaces in the detachable weighing bo (F, F′, and G). The weighing bottles and contents weighed on a balance which carries 2000 g and respond 0·005 g. Both sides of the apparatus are connecte vacuum and gas preparation lines outside the thermo Fine control of the mercury surfaces in the dead space obtained by the mercury micrometer pipette at *H*. This steel plunger operating by a fine screw thread in a clo fitting cylinder of 3 mm diameter and sealed by a neopr ring. It is located more than 76 cm below the level of

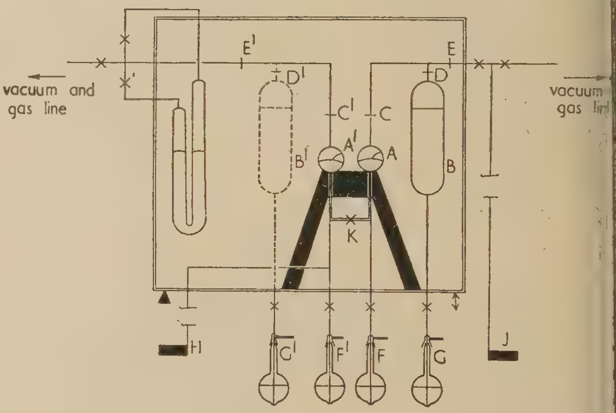

Fig. 1. General experimental layout of differenti manometer system

X = conventional greased tap or suitable grease-free valve atus to prevent inward leakage of air. The quantity of ıry in the dead space system can be controlled over a of 0·2 cm^3 by increments as small as 0·0002 cm^3, h no volume measurements are made by means of the e. There is a similar pipette at *J*.

ore use the apparatus is rinsed thoroughly with dry gen and evacuated by diffusion pump for many hours. essential operation of setting the tungsten reference s to horizontality is then carried out by rotating the apparatus and thermostat in the vertical plane by fine d screws, until the mercury surfaces in both evacuated spaces are just set to the tungsten reference points. evel is maintained throughout the subsequent operations eans of a sensitive spirit level attached to the rigid dead assembly. The volume of the capillary tubing *CDE* he volume per unit length of the tube at *E* are then nined by weighing mercury into the detachable bottles. e apparatus is prepared for use as a pressure measuring ıment by the following operations, The mercury in the ler is set to mark *D*, and a volume of about 100 cm^3 is ated by running the mercury out of the cylinder into *G*. The mercury in dead space *A* is set approximately e tungsten reference point with the inter-connecting tap sed. Nitrogen, dried by passage through a liquid air d trap, is admitted to the volume so generated and ıed by advancing a mercury surface from outside the ıostat to *E*. The dead space *A′* and the 20 mm bore meter inside the thermostat are filled to a similar ure. Tap *K* is opened and the pressure on the left-hand adjusted until the mercury surfaces in the dead spaces losely set to the reference points. Tap *K* is closed and pressure given by the manometer is determined as ately as possible by cathetometer measurement. ury is run from the weighed bottle *F* into dead space *A* the mercury sets to mark *C*; the bottle is then reweighed. volume of nitrogen on the right-hand side is the sum of olumes corresponding to the masses of mercury in the sections: dead space surface to mark *C*; cylinder sur- to mark *D*; and the previously calibrated volume *CDE*. total volume can be determined in this way to better one part in 100 000. The nitrogen on the left-hand side mped off.

gas pressure of experimental interest is then applied to space *A′*. Tap *K* is opened and the nitrogen volume on right-hand side adjusted to balance the new pressure. se adjustment is made by running mercury from the der into bottle *G*; the fine adjustment is made by minor ations in the position of the mercury surface at *E* by the ometer at *J*. Adjustment of the mercury in the dead es is made as required by using bottles *F* and *F′*, and the ometer at *H* for the fine adjustment. When exact ıce is obtained tap *K* is closed and the new volume of the ence gas again determined from the sum of the three s.

WORKING TEST OF APPARATUS

demonstrate the reproducibility of the point setting, the cipal uncertainty in the equipment used, a second der *B′* (shown dotted in Fig. 1) attached to dead space vas introduced, together with an additional weighing e *G′* and reference marks at *E′*, *D′* and *C′*. Samples of gen were admitted to each cylinder and the volumes mined when the pressures were equal. The ratio of volumes should be independent of the pressure. Varia- in the volume ratio indicate errors in the point settings. technique is a modification for use in the pressure range 20 to 200 mm of the differential expansion apparatus previously described by Bottomley, Massie and Whytlaw-Gray,(1) and by Reeves and Whytlaw-Gray.(2)

The table shows the results of two typical experiments starting at 200 and 100 mm respectively and covering a pressure range of about four to one. The volume determination in these experiments is subject to errors from the weighings of mercury and from the setting and reading of various mercury surfaces in relation to fiducial marks. The combination of these errors is estimated to be about one part in 100 000 on a single volume determination. The results of experiments (1) and (2) demonstrate clearly that the pressure equality between the two sides can be achieved to well within two parts in 100 000 at pressures as low as 25 mm. The determined values of the nitrogen volumes on one side of the apparatus combined with the initial nitrogen volume at the highest pressure serve to define the successive pressures relative to the first pressure within one or two parts in 100 000.

Specimen expansions with dry nitrogen in each cylinder

Approximate pressure (mm of mercury)	*Volume ratio*
Experiment (1) *at* 50° *C*	
200·1	1·014132
165·7	1·014143
131·8	1·014131
98·34	1·014130
54·53	1·014138
Experiment (2) *at* 22° *C*	
100·2	1·017711
68·75	1·017714
43·32	1·017720
27·53	1·017717

As the above results indicate the extraordinary delicacy of the point setting operation we give some further pertinent experimental details. The dead spaces are in the form of spherical bulbs 34 mm internal diameter, wall thickness 4 mm, each with a carefully centred tungsten reference point attached to the glass below the mercury level. It is necessary to have the working meniscuses so large in diameter to avoid variations in the capillary depressions, which would vitiate the condition of pressure equality at a setting. As the volume between the mercury surface in the dead space and the reference mark is measured at each setting no volume error can arise from variations in meniscus height, shape or contact angle. In current practice the dead space volumes show a general scatter of ±0·05 cm^3, with occasional variations as large as ±0·15 cm^3. From the tables for meniscus surfaces of Porter(3) and Kistemaker(4) it may be shown that the corresponding capillary depression variations are of the order of 0·0001 mm. With any reduction in diameter of dead space below 34 mm, the variation of capillary depression with meniscus height rises rapidly to figures which indicate that it may be difficult to ensure adequate pressure equality between the two sides. For instance, at 29 mm diameter the variation is almost four times as great as at 34 mm. No reasonable variation of the surface tension of the mercury can affect the capillary depression in the two dead spaces sufficiently to cause appreciable error in the attainment of the pressure equality. If one dead space contains a vapour very near to its saturation pressure (when considerable lowering of the interfacial tension by adsorption of the vapour may occur) then the capillary depressions may differ significantly.

An increase in dead space diameter to 40 mm would then be desirable so as to bring the actual depression to less than 0·0002 mm and the variations to much less than 0·0001 mm.

The movement of the mercury in the extremely dry apparatus generates considerable quantities of static electricity. Experiments with a valve voltmeter when the thermostat tank is empty show that external potential gradients as high as 100 V/cm are readily produced and remain with only slight loss during some hours. If glass points are used the static electricity distorts the mercury meniscus upwards locally at the point as the setting is approached, and fine adjustment is then impossible. By using tungsten points curved over to make a metallic contact with the mercury the distortion difficulty is overcome.

A secondary effect is that the observed volume ratio between the two sides may change up to fifty parts in 100000 in the first few hours after the manipulation of the mercury in the cylinders. This effect is most pronounced at or below room temperature, at the lowest pressures, when the apparatus and gas samples are most carefully desiccated, and especially so when organic vapours are under examination. For work of the highest precision at least eighteen hours should be allowed before the final setting of the points is attempted. This effect is not fully understood; possible explanations are: electrostriction brought about by static electricity, a changing adsorption of the vapour on the various interfaces influenced by the static electricity, or a slow saturation of the gases with mercury vapour.

The points are formed from tungsten rod 1 mm diameter ground to an included angle of about 10° on a fine grinding wheel and then smoothed at the tip by wiping when red-hot with a stick of sodium nitrite. Several points are made at once and a pair approximately matched by viewing under the microscope at a magnification of sixty times.

POINT-SETTING PROCEDURE

The optimum viewing conditions for point setting are obtained with the components spaced as shown in Fig. 2. The observer examines the mercury surface through a 10 cm focal length convex lens with his eye very close to the front surface of the thermostat and at an angle about 8° from the horizontal, so that the mercury surface appears as a narrow ellipse reflecting the even illumination of the diffusing paper surface. The mercury surface is advanced by the introduction of increments of a few cubic millimetres of mercury until the point and its image are separated by about 0·1 mm. The blackened shield, about 2·5 cm deep, is lowered into the tank until the upper edge of the somewhat out-of-focus im reflected in the mercury surface bisects at right angles point-image line at the level of the gap. This condition be maintained as quantities of mercury, gradually decrea in size to one or two tenths of a cubic millimetre, are in duced by the micrometer pipette until the appear indicative of the point touching is obtained.

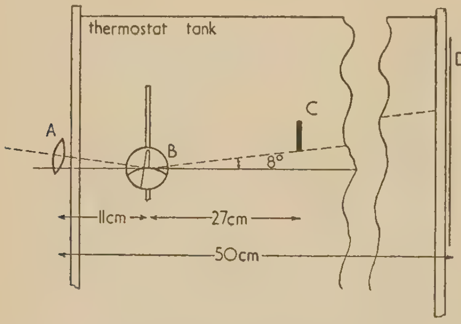

Fig. 2. Recommended optical lay-out. (Side elevation)

A, 10 cm focal length hand lens; *B*, dead space with tungsten point and mercury surface; *C*, section of metal shield; *D*, Uniformly illuminated translucent paper.

With the illumination system as described, the point its image, quite black against the white background, are at first separated by a narrow gap which becomes q invisible with the approach of the mercury surface. contact, a short black line, the length of which is s measure of the degree of oversetting of the surface, app at right angles to the tip. The operator lowers the mer surface until the characteristic setting line disappears makes a more carefully controlled approach to the set point. The change from no visible line to one of le about 0·1 mm occurs over an increment of 0·2 mm^3 i dead spaces used, corresponding to a height change of a 0·0002 mm at the meniscus vertex.

The manner in which the line across the point is forme as follows. The observer views the mercury surface at an angle that the reflexion of the lower edge of the sh lies across the point-image intersection: the mercury sur nearer the observer than the point, being viewed at a ste angle, reflects the body of the shield and appears dark; mercury surface more remote from the observer, being vie at a shallower angle, reflects the light from the diffusing and appears white. Once contact has been made, the tung point forms a small dimple in the mercury surface by capi action. The remote part of this depression lies more n normal to the observer's line of view than the plane o undisturbed surface, reflects the image of the black s and so forms the characteristic line. Similarly, the par the depression not immediately behind the point reflect black shield, the effect decreasing as the left- and right-h extremities of the depression are approached.

The viewing method is similar to that of testing a mi for zonal irregularities by the Foucault knife-edge test. mercury surface replaces the mirror and the shield the kn edge. Before contact is made the mercury surface app

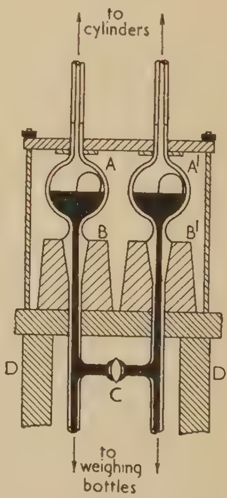

Fig. 3. Details of dead space assembly

A, *A′*, dead space with tungsten point; *B*, *B′*, ground co and socket locating dead space in rigid fashion; *C*, inte communication tap operated from outside thermosta *D*, *D′*, heavy metal supports welded to floor of thermostat tan uniform as the image of the shield is scanned backwards orwards over the area close to the point-image junction nall vertical movements of the observer's head. After ct the local irregularity in the "figure" of the mercury the point shows up very pronouncedly. This com- on helps to explain the extraordinary delicacy of the or point-mercury contact. In practice, since it suffices roper working to bring the two sides of the apparatus e same pressure, a very slight "over-setting" on one side e used as a reference against which to "over-set" the side.

me care in avoiding accidental disturbance of the ury surfaces in the dead spaces is necessary for proper g. In the latest form of the apparatus (Fig. 3) the dead s are rigidly mounted by carefully ground cones and ts in a heavy metal structure welded to the floor of the nostat tank. Though the use of a special isolated atory would have been a convenience, the rigidly-built nostat tank is installed in a ground-floor room on a heavy rete floor. Transient disturbances occur if the thermostat is jarred and when personnel in adjacent laboratories heavily. A much more serious difficulty is the for- on of standing waves on the mercury surfaces by nance with the mechanical action of stirrers, vacuum ps, electric fans, air compressors and the like. The nostat stirrer, which is mounted from the ceiling quite pendently of the tank, gives little trouble in this respect.

e literature contains very little information on setting a point to a mercury surface. Rayleigh[(5)] claims that "the errors of setting are considerably less than 1/1000 millim."; 0·0005 mm is claimed[(6)] for a method using the distortion of a reflexion of a fine scale by the penetration of the point into the surface. In general, however, the extraordinary delicacy of the contact has not been pressed to its limits in metrology. The Rayleigh manometer, using a built-in ladder of points as an internal scale, is capable of much greater precision than the conventional cathetometer methods. If such an instrument, used for the determination of the initial absolute pressure measurement, were combined with the technique described in this paper, then there seems no reason why absolute pressure measurements reliable to 0·002 mm of mercury or better should not be conveniently attained.

REFERENCES

(1) Bottomley, G. A., Massie, D. S., and Whytlaw-Gray, R. *Proc. Roy. Soc. A.*, **200**, p. 201 (1950).

(2) Reeves, C. G., and Whytlaw-Gray, R. *Proc. Roy. Soc. A.*, **232**, p. 173 (1955).

(3) Porter, A. W. *Trans Faraday Soc.*, **29**, p. 1307 (1933).

(4) Kistemaker. *Physica*, **11**, p. 270 (1945).

(5) Rayleigh, Lord. *Phil. Trans A*, **196**, p. 205 (1901).

(6) Glazebrook, R. (Ed.). *Dictionary of Applied Physics*, Vol. 3, p. 151 (London: Macmillan and Co. Ltd., 1923).

On numerical Fourier transformation, with special reference to Lipson–Beevers strips

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Lipson–Beevers strips have been used in trials aimed at illustrating, in two special cases, the effect of rounding-off errors in numerical Fourier transformation. No evidence has been found to support the suggestion, sometimes put forward by false analogy with the Gibbs phenomenon, that such errors lead to systematically oscillatory residuals in the calculated ordinates.

1. INTRODUCTION

A_n be a set of complex ordinates at equal intervals of r argument, where $-N+1 \leqslant n \leqslant N$. Then the nates B_m of the Fourier transform of the A_n are usually ulated numerically by the formula

$$B_m = \sum_{n=-N+1}^{N} A_n \exp\left(i\pi \frac{nm}{N}\right) \qquad (1)$$

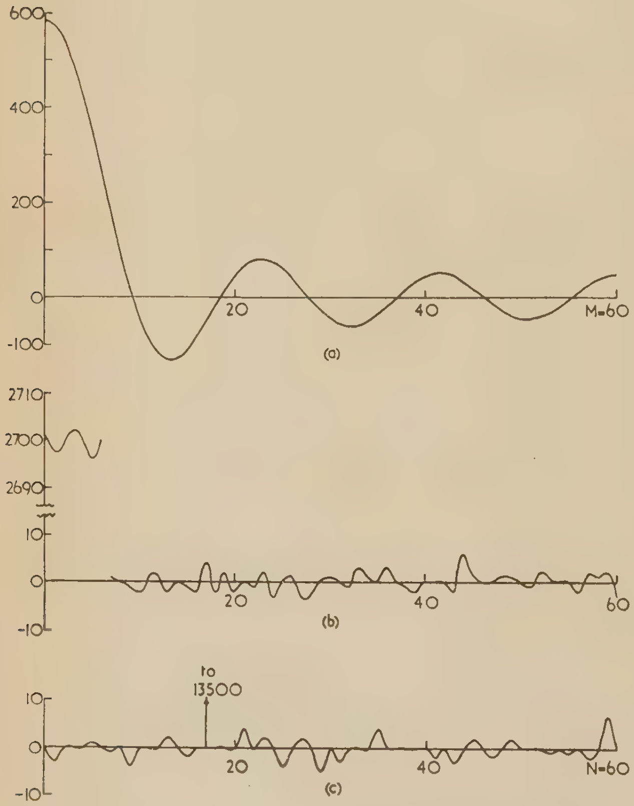
re in practice the real and imaginary, and the sine cosine, portions of the transform are dealt with rately.

lany of the important and well-known uses of Fourier hods depend on the fact that when the Fourier operation erformed twice on a function, the original function is der suitable conditions) recovered. Depending on the ct form of Fourier operation used, the recovered function may or may not be mirror-imaged with respect to the original about the origin of co-ordinates; however, it is straightforward in numerical work to combine the odd and even parts of a calculated transform in the right way to avoid mirror-imaging.

It is easily seen that the operation of equation (1), interpreted in this way, does have the property that when it is performed twice the original ordinates are recovered, apart from a re-normalization by a factor N. However, fears have sometimes been expressed that the rounding-off errors inherent in any numerical method would disturb this property in a practically objectionable way by combining systematically to give an oscillation of relatively large amplitude in the neighbourhood of any sudden change in the run of the A_n. There is in fact no theoretical reason to expect this to happen with high probability in normal cases, and the fear appears to have been aroused by the existence of the Gibbs phenomenon.

A suspicion of this kind is not easy to lay. If arguments can be adduced for a belief, it is open to an objector to refute these arguments; but where no reasons are put forward it is hard for the objector to give positive reasons against the belief. Accordingly it was felt that a numerical demonstration would be of value, although it is of course inferior in logical force to a theoretical proof.

The printed cardboard strips developed by Lipson and Beevers(1) as an aid to Fourier calculations in X-ray crystallography, have long been used for more general Fourier calculations.(2) The strips can be arranged in rectangular arrays such that the operation of equation (1) can be performed by simply adding columns of printed figures. Although this method must now be regarded as obsolete for large-scale work to anyone who has access to a modern computing machine, the strips remain an excellent tool for gaining an appreciation of the numerical properties of the Fourier operation, and for exploratory investigations in which it is necessary to vary the approach in accordance with the behaviour of the data. The original description(1) should be consulted for details of the strips. For the present purpose, all that is essential is that the strips have printed on them the values of $a \cos (nm \times 3°)$ and $a \sin (nm \times 3°)$ rounded off to the nearest integer, where $-1000 < a < 1000$, $-60 \leqslant n \leqslant 60$, $-60 \leqslant m \leqslant 60$; a, n, m integers. The B_m are formed by adding these entries. Evidently this form of rounding-off is typical of numerical methods for the desired operation.



Plot of transforms of (*a*) a rectangular distribution, (*b*) transform of (*a*), (*c*) transform of a cosine distribution

Curves (*b*) and (*c*) show the approximate recovery of the respective original distributions, and illustrate the behaviour of the residuals near to discontinuities in the run of the recovered ordinates.

2. THE TRIAL CALCULATIONS

Repeated Fourier transformation has been carried using the strips on the following two sets of ordinates

$$(a)\ A_n = \left| \begin{array}{l} 450,\ |n| \leqslant 6 \\ 0,\ |n| > 6 \end{array} \right. \qquad (b)\ A_n = \left| \begin{array}{l} 225,\ |n| = 17 \\ 0,\ |n| \neq 17 \end{array} \right.$$

The transform B_m of set (*a*), divided by 10, is plotte Fig. 1(*a*). The form of the curve is closely related tc sinc function [$\operatorname{sinc} x \equiv \sin (\pi x)/\pi x$]. The transforn set (*b*) is of course a cosine curve with amplitude 450.

The transforms of these two sets of B_m are plotte Fig. 1(*b*) and (*c*) respectively. The re-normalizing fa $N = 60$ applies as it stands to the double transform of se In the calculation of the second transform for set (*a*) it necessary (as indicated above) to divide by 10 in orde make the values handled appropriate to the range of ar tude a of the strips; this gives an overall normalizing fact

3. CONCLUSIONS

It will be seen that the (re-normalized) ordinates of original sets (*a*) and (*b*) are recovered with good accur and that there is no tendency for the residuals to osci systematically in the neighbourhood of a jump in the va of the ordinates.

Reference to the instructions for using the strips shows the ordinates to be transformed are first combine "folding" about $n = 30$ (or $m = 30$ as the case may be as to form $a_0 + a_{60}$, $a_0 - a_{60}$, $a_1 + a_{59}$, $a_1 - a_{59}$ Each ordinate of the transform is then obtained by ad 30 entries on the strip of the form

$$(a_m \pm a_{N-m})\binom{\sin}{\cos}(nm \times 3°)$$

In the present calculations, the combined amplit $a_m + a_{N-m}$ were rounded off to the nearest integer after folding process. Each of the 30 numbers to be added has an r.m.s. error due to its own rounding off of 0·29 u and an additional error of $(0{\cdot}29)/\sqrt{2}$ r.m.s. due to rounding off error in the amplitude which multiplies Thus the total error to be expected in the sums of the numbers is approximately $\sqrt{3/2}\,.\,\sqrt{30}\,.\,0{\cdot}29 = 1{\cdot}9$ r In the case of set (*b*) there is a small additional error beca the amplitudes used in the second transformation may slightly affected, even after the division of 10, by error the first transformation. The actual r.m.s. residuals fo are 1·85 for set (*a*) and 1·82 for set (*b*).

These trials do not of course exclude the possibility the rounding-off errors may sometimes behave pathologica but they do tend to give confidence that numer Fourier transformation on Lipson–Beevers strips, or by numerical(3) or mechanical(4) method involving sim rounding-off, is not likely in normal cases, and where reas able precautions are taken, to be vitiated by systematic oscillatory residuals.

REFERENCES

(1) Lipson, H., and Beevers, C. A. *Proc. Phys.* *[London]*, **48**, p. 477 (1936); *Nature* [*London*], p. 825 (1936).
(2) Ross, M. A. S. *Nature* [*London*], **152**, p. 302 (1943).
(3) Robertson, J. M. *J. Sci. Instrum.*, **25**, p. 28 (1948).
(4) Macewan, P., and Beevers, C. A. *J. Sci. Instrum.*, p. 150 (1942).

A portable apparatus for recording the rate of clearance of radioactive sodium from human calf muscle

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The apparatus consists of a halogen quenched Geiger–Müller counter which straps over the muscle to be tested and a light pack which is carried on the subject's back. The pack contains, in addition to batteries, the high tension generator for the counter, an electronic circuit in which alternate pulses from the counter are used to trigger a pulse generator, a wire recorder to record the pulses and a ratemeter for monitoring purposes.

The record obtained on the wire recorder is subsequently played back in the laboratory, and after amplification the pulses are fed back into the monitoring ratemeter, the output from which is amplified and used to drive a recording milliammeter.

INTRODUCTION

s been established that changes in the rate at which an tion of isotonic radioactive sodium chloride is cleared human calf muscle reflect changes in the blood flow ugh the muscle.(1) This observation has been used to stigate blood flow during exercise in normal subjects and suffering from impaired circulation to the muscle.(2) to now the exercise has been limited in scope because he nature of conventional Geiger–Müller counting pment. The exercise has consisted of rhythmically racting the calf muscles under investigation by raising ody up on to the toes of that side and lowering it down n in time with a metronome.

bservations made during this type of exercise have given able information, but the need to extend the investigation clude the changes in clearance rate during the exercise alking has resulted in the construction of the apparatus ribed here.

g. 1 shows schematically the arrangement of the apparatus ng recording and during playback.

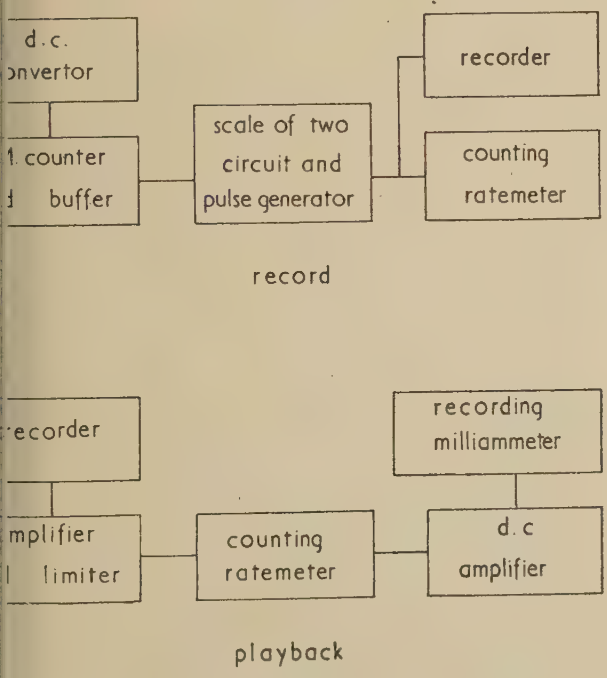


Fig. 1. Block diagram of the complete equipment

RECORDING

The Geiger–Müller counter (type G4H by 20th Century Electronics Ltd.) together with a buffer circuit is mounted in a sorbo rubber pad which straps over the site of injection of the radioactive sodium chloride. The rest of the apparatus is carried in a pack mounted on a haversack frame. The high voltage supply for the Geiger–Müller counter tube is generated from a 4·5 V dry battery by using a transistor convertor.(3) The output of the convertor is maintained at 350 V by a Corona stabilizer.

The pulses from the Geiger–Müller tube are passed through a scale of two circuits which only allows alternate pulses to trigger the pulse generator. This halving of the frequency enables the use of a sufficiently large dose of radioactive sodium chloride to give good discrimination against the background count whilst keeping the pulses to be recorded within the frequency range of the wire recorder. The ratemeter consists of a lightweight counting circuit as described by Molyneux(4) modified to the required working range of 500 p.p.s. This circuit produces a current directly proportional to the frequency of the counts. The counting rate is displayed on a microampmeter visible through a window in the pack and is recorded on a Minifon wire recorder (by Protona GMBH, Hamburg). The power to drive the motor of this latter instrument is supplied from accumulators.

PLAYBACK

The output from the head of the wire recorder is amplified and passed through a limiting stage, which effectively separates the pulses from background noise. These pulses are then passed into the ratemeter referred to above and the output current amplified to a level sufficient to drive a recording milliammeter.

The transistor circuits (except for the Geiger–Müller tube h.t. supply and the ratemeter) are new in the sense that they were designed especially for this apparatus. A full circuit diagram is given (Fig. 2) and it is possible to make the apparatus from this alone, as no critical adjustments are necessary.

PERFORMANCE OF THE APPARATUS

When tested with regularly spaced pulses derived from a signal generator the apparatus recorded and reproduced faithfully (linearity better than ±5%) up to 1000 pulses per

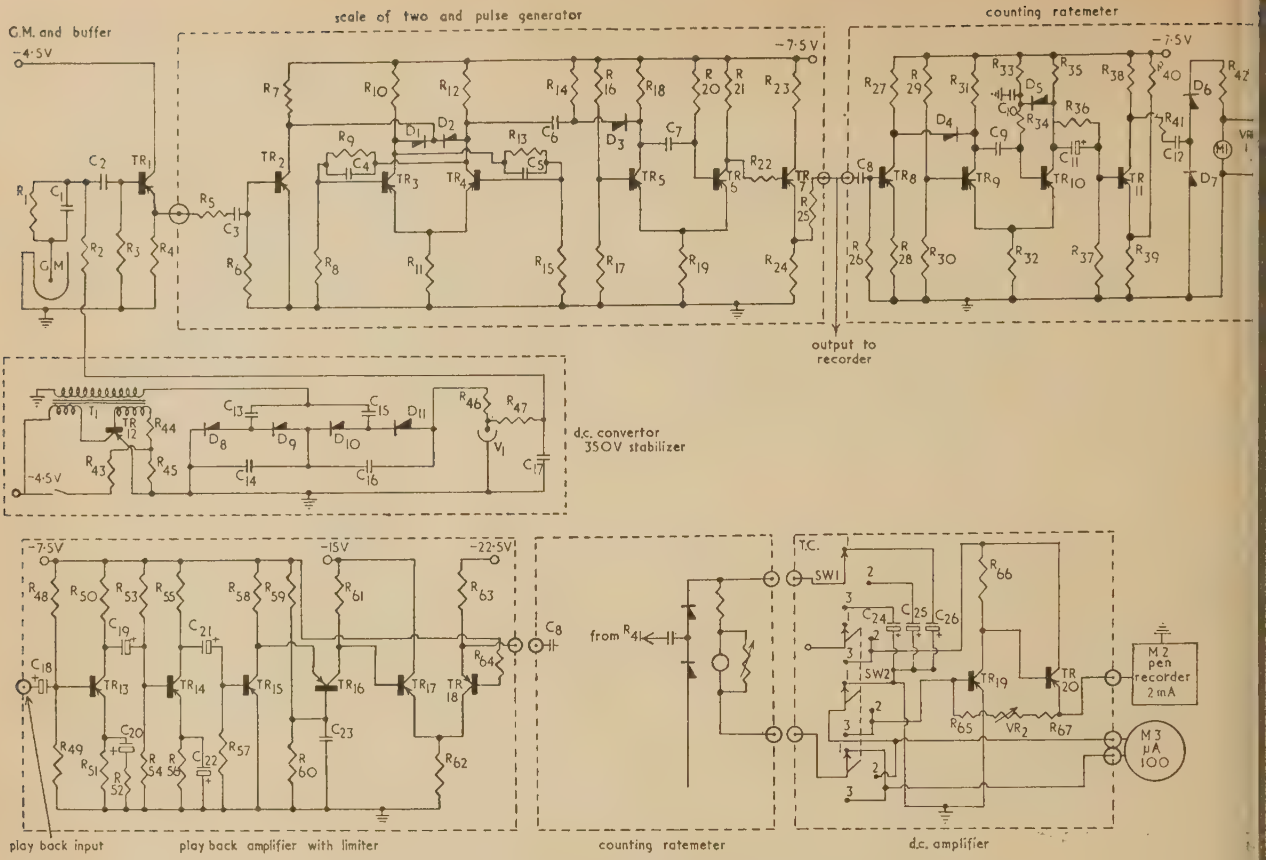

G.M. and buffer
−4·5V
scale of two and pulse generator
−7·5V
counting ratemeter
−7·5V
output to recorder
d.c. convertor 350V stabilizer
−4·5V
−7·5V
−15V
−22·5V
play back input
play back amplifier with limiter
counting ratemeter
from R41
T.C.
SW1
SW2
d.c. amplifier
M2 pen recorder 2 mA
M3 µA 100
GM
TR1
TR2
TR3
TR4
TR5
TR8
TR9
TR10
TR11
TR12
TR13
TR14
TR15
TR16
TR17
TR18
TR19
TR20
M1
V1
T1
VR1
VR2

Fig. 2. Recording and playback circuits

R_1 = 10 MΩ
R_2 = 2·2 MΩ
R_3 = 2 MΩ
R_4 = 20 kΩ
R_5 = 10 kΩ
R_6 = 1 MΩ
R_7 = 10 kΩ
R_8 = 50 kΩ
R_9 = 100 kΩ
R_{10} = 6·8 kΩ
R_{11} = 1 kΩ
R_{12} = 6·8 kΩ
R_{13} = 100 kΩ
R_{14} = 47 kΩ
R_{15} = 50 kΩ
R_{16} = 5·6 kΩ
R_{17} = 110 Ω
R_{18} = 15 kΩ
R_{19} = 320 Ω
R_{20} = 470 kΩ
R_{21} = 6·8 kΩ
R_{22} = 10 kΩ
R_{23} = 470 Ω
R_{24} = 6·8 kΩ
R_{25} = 10 kΩ
R_{26} = 100 kΩ
R_{27} = 22 kΩ

R_{28} = 22 kΩ
R_{29} = 5·6 kΩ
R_{30} = 110 Ω
R_{31} = 15 kΩ
R_{32} = 330 Ω
R_{33} = 200 kΩ
R_{34} = 82 kΩ
R_{35} = 6·8 kΩ
R_{36} = 22 kΩ
R_{37} = 2·2 kΩ
R_{38} = 2·2 kΩ
R_{39} = 100 Ω
R_{40} = 2·2 kΩ
R_{41} = 1 kΩ
R_{42} = 2·7 kΩ
R_{43} = 2 kΩ
R_{44} = 4·7 kΩ
R_{45} = 100 Ω
R_{46} = 22 MΩ
R_{47} = 2·2 MΩ
R_{48} = 220 kΩ
R_{49} = 100 kΩ
R_{50} = 6·8 kΩ
R_{51} = 2·7 kΩ
R_{52} = 2·7 kΩ
R_{53} = 220 kΩ
R_{54} = 100 kΩ

R_{55} = 6·8 kΩ
R_{56} = 2·7 kΩ
R_{57} = 100 kΩ
R_{58} = 6·8 kΩ
R_{59} = 1·5 kΩ
R_{60} = 3 kΩ
R_{61} = 50 kΩ
R_{62} = 33 kΩ
R_{63} = 50 kΩ
R_{64} = 1 kΩ
R_{65} = 15 kΩ
R_{66} = 33 kΩ
R_{67} = 47 kΩ

VR_1 = 5 kΩ
VR_2 = 25 kΩ

C_1 = 3 pF
C_2 = 15 pF
C_3 = 0·01 µF
C_4 = 0·01 µF
C_5 = 0·01 µF
C_6 = 0·0005 µF
C_7 = 0·01 µF
C_8 = 0·0005 µF
C_9 = 0·015 µF
C_{10} = 0·1 µF

C_{11} = 10 µF
C_{12} = 0·04 µF
C_{13} = 0·005 µF
C_{14} = 0·1 µF
C_{15} = 0·005 µF
C_{16} = 0·1 µF
C_{17} = 0·01 µF
C_{18} = 50 µF
C_{19} = 10 µF
C_{20} = 10 µF
C_{21} = 25 µF
C_{22} = 10 µF
C_{23} = 0·1 µF
C_{24} = 10 µF
C_{25} = 100 µF
C_{26} = 1000 µF

V_1 = GD350X

GM = G4H 350 V

TR = OC71, all except
TR_{12}, TR_{20} = OC72

D_1 = OA73
D_2 = OA73
D_3 = OA73

D_4 = OA71
D_5 = OA71
D_6 = OA73
D_7 = OA73
D_8 = K3/10
D_9 = K3/10
D_{10} = K3/10
D_{11} = K3/10

M_1 = 0–100 µA
M_2 = 2 mA Pen Recorder [by Elliott Bros. (London) Ltd.]
M_3 = 0–100 µA

SW_1 = 1-pole, 3-way
SW_2 = 3-pole, 3-way

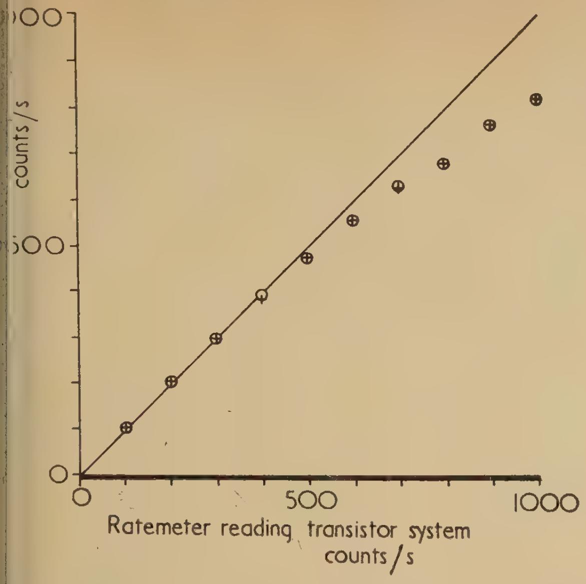
T_1 = Core. Two Ferroxcube "E"s No. FX 1239 (by Mullard Ltd.)

Bobbin RM 269 (by Rootes Mouldings Ltd.)—

Primary	132 turns	33 s.w.g.
Base	33 turns	33 s.w.g.
Secondary	3300 turns	47 s.w.g.

second. The wire recorder has a mechanical governor to control its speed and the motor is supplied by accumulators (by Venner Ltd.) working on the flat part of their discharge characteristics. With this arrangement a particular pulse rate is reproduced to an accuracy of better than ±5%. The use of transistors immediately following a Geiger–Müller tube is not yet common practice so that the following tests were carried out to ensure that the adopted circuit had an adequate performance.

The apparatus is intended for relative measurements of radio activity and it was compared with a conventional apparatus in the following way. The Geiger–Müller tube was so arranged that it could be connected either to a standard apparatus (ratemeter type N522 by Ekco used with maker's recommended input circuit) or to the portable appara When the portable apparatus was in use the ratemeter arranged to indicate the rate at which pulses were fed to recording head. Subsequently when the recordings played back the ratemeter was used to indicate the rat the recorded pulses. An ampoule containing radioac sodium chloride was placed at various distances from Geiger–Müller tube and the ratemeter reading noted for two pieces of apparatus alternately. This data together the ratemeter readings on playback is plotted in Fig The readings of the ratemeter for both sets of data rela to the portable apparatus have been multiplied by tw order to compensate for the scale of two circuit in portable equipment. It can be seen that below 400 p



3. Relationship between counting rates as recorded by conventional system and transistor system

there is a linear relationship between readings obtained using the standard apparatus and those obtained using the portable apparatus. As the counting rates used in practice are below 400 p.p.s. the circuit was deemed satisfactory.

CONSTRUCTION

The circuits are contained in aluminium boxes which correspond to the dotted lines on the circuit diagram. The size of the pack containing the equipment carried by the subject under investigation is 27 × 30 × 14 cm and its weight 3·6 kg.

ACKNOWLEDGEMENT

The practical details of the transistor convertor as described by Light and Hooker were made available to us through the courtesy of Mullard Ltd.

REFERENCES

(1) Walder, D. N. *Clin. Sci.*, **12**, p. 153 (1953).
(2) Walder, D. N. *Brit. Med. Journal*, **1**, p. 255 (1958).
(3) Light, L. H., and Hooker, P. M. *J. Instn Elect. Engrs*, **102** (B), p. 775 (1955).
(4) Molyneux, L. *Electronic Engng*, **29**, p. 125 (1957).

Jigs for making crystallographic wire models

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Models made from stiff wire, in which the bends, junctions and free ends represent atomic centres, are often used in structure-determination and other crystallographic problems but are not easy to make accurately. Two jigs are described, one for making successive bends in a single piece of wire and the other for clamping wires in the correct relative orientations while soldering. They permit models to be made rapidly by a comparatively unskilled operator.

1. INTRODUCTION

al structure problems are essentially three-dimensional, scale models often play an important part at different s in their solution. Many methods of constructing els have been advocated at various times;(1, 2) the choice s to be largely a matter of personal preference. One ly used method of construction is to bend and solder hs of stiff wire so that the bends, junctions and free ends sent atomic centres. This kind of model is particularly l in relating a three-dimensional structure to its pro- ns on various planes by means of mirror methods(3) or arallel beam projection;(4) the absence of large spheres e atomic centres simplifies the problem of centre-location there is considerable overlapping in the projection. e models are also valuable in optical transform work diffracting masks may be made, with a pantograph h,(5) direct from the model without an intermediate ing stage. Their disadvantage, however, has been that, s one happens to be particularly skilful at manipulation, not easy to produce models—particularly of large non- ar molecules—with very high precision. The present r describes two jigs by means of which a comparatively illed operator can make models quite rapidly and with ient accuracy for most purposes.

e first jig to be described—the bending jig—is used to successive bends in a single length of wire and to ide a control of the angles between the various bonds also of the angles between the planes in which the various s are made. The second—the brazing jig—is a clamping device designed to hold two wires, or two portions of a model, and to provide enough degrees of freedom to permit the angles at the join and the angles between the planes of the bends adjacent to the join to be adjusted as required. A small electric arc welder has been found convenient for brazing the wires together and a note on its use is included.

Full details of the construction, materials and dimensions are not given, except where matters of principle are involved, since the actual jigs described were made largely from war surplus materials and the design details were influenced by the available components. The principles are, however, fully described with sufficient details of construction to permit similar instruments to be made with whatever resources happen to be available. Some practical notes on technique are also given. Both the jigs described have been designed to work well with models of organic molecules on scales of 2 cm to 1 Å or 1 in. to 1 Å. Simple modifications of the same basic principle could easily be made for models of other kinds.

As an example of the work done with these jigs, Fig. 1 is a photograph of a model of a sodium benzyl penicillin molecule correctly oriented in a parallel beam of light over an electron density map of the (010) projection of the structure. The data from which the model was produced and the electron density map were taken from the account of the structure determination by Crowfoot, Bunn, Rogers-Low and Turner-Jones.(6) Further details of this model are given in Section 4.

2. THE BENDING JIG

2.1 *Principle.* The successive operations to be performed by the bending jig are illustrated in Fig. 2. The wire *AF* [Fig. 2(*a*)] is to be bent successively at the points *B*, *C*, *D* and *E* and the bends are not necessarily to be in the same plane. The first operation is to make a bend of the required angle at *B*. Fig. 2(*b*) shows this stage completed. The plane in which this bend is made—defined by *A*, *B* and *C*—is assumed to be the plane of the diagram.

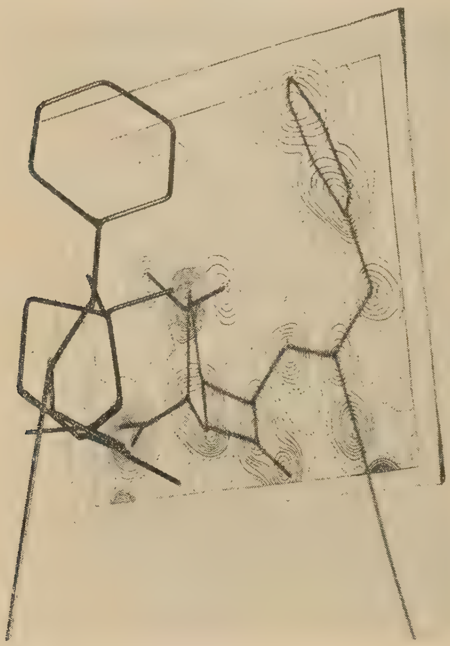


Fig. 1. A model made with the jigs. The sodium benzyl penicillin molecule is correctly oriented in a parallel beam of light over the (010) Fourier projection of the electron density

It is convenient to make the bends always at the same part of the jig—that is to move the wire in between each bend—and to make the bends always in the same plane. The jig must therefore provide for translation of the wire a measurable distance [Fig. 2(*c*)] and for rotation of the plane *ABC* about the common line *BC* as axis until it makes the required angle with the plane in which the bend *BCD* will be made; that is, the plane of the diagram [Fig. 2(*d*)]. A bend made at *C* as shown in Fig. 2(*e*) in the plane of the diagram is the next operation required. The procedure for the bend at *C* may then be repeated at *D* and so on. If planar molecules are being made, the rotation illustrated by Fig. 2(*d*) is obviously unnecessary.

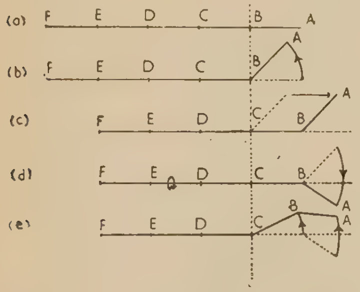


Fig. 2. Sequence of operations performed by the bending jig

2.2 *Construction.* The jig consists of three main units, each designed to provide one of the movements illustrated in Fig. 2. Fig. 3 shows the general arrangement. carriage *F* [Figs. 3(*a*) and (*b*)] controls the position wire in the jig—the movement illustrated in Fig. 2(*c*). rotating unit *G* [Figs. 3(*a*) and (*b*)] controls the angle be the planes of successive bends—the movement illustrat Fig. 2(*d*). Unit *G* is carried by the third unit *H* [Figs and (*b*)]—the bending unit—which controls the move illustrated by Figs. 2(*b*) and (*e*).

The wire, shown as a thick line in Fig. 3, is clamp the bush *I* by the screw *J* so that it has no transla degrees of freedom with respect to the carriage but the bush may rotate, in a bearing fixed to the carriage, the length of the wire as axis to permit the moveme Fig. 2(*d*). The whole carriage *F* can move along the sli and a scale K_s is provided, so that the distance moved be bends—that is the bond lengths—can be controlled. carriage may be clamped at any point by the screw prevent movement during bending.

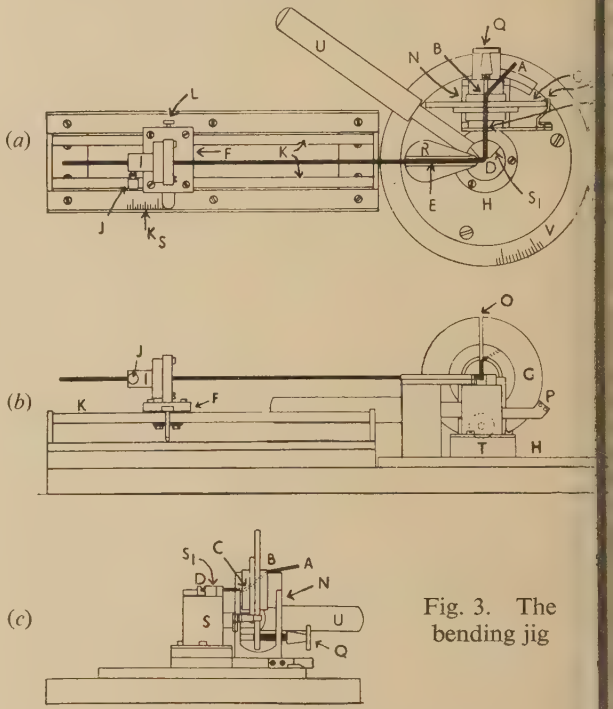


Fig. 3. The bending jig

The wire passes through the bending unit *H* to the rot unit *G*. In Fig. 3 the wire has just been bent at *D*, th bends at *B* and *C* having already been made. The between the planes *BCD* and *CDE* was made 90° an bend at *D* was also made 90° so that the parts of the i ment are conveniently arranged in the drawings. rotating unit consists of a disk free to rotate in a half be *N*—necessary, as will be explained later, to permi removal of the wire from the jig between successive be and having a radial slot *O* extending from the edge c disk to the axis of rotation. A scale of degrees is eng on the disk. Before the bend *D* is made this unit is i with the unused length of wire, and clearly, rotation c disk, indicated by the pointer *P*, controls the angle bet the plane *BCD* and *CDE*, the latter, of course, rema horizontal throughout the bending operation. The rot unit *G* may be clamped by the screw *Q* to prevent rot and movement out of the half bearing.

The bending unit itself consists of a fixed portio which remains in line with the unused wire, and a rot on S_1. The fixed portion consists of two guides between n the wire is free to slide. The rotating portion consists similar, though shorter, guide integral with the pillar *S* n can rotate in a ball race at *T*. It is necessary that this ng should be free from play and capable of standing a in amount of stress. A handle *U* is screwed into *S* to de the necessary leverage and control in making the . The angle of the bend is measured on the scale *V*.

Use. It has been found that welding rod (copper-d steel) is very suitable for making models; it is soft gh to bend easily, stiff enough to retain its shape and to braze. The jigs described have been made to take) in. diameter rod.

length of wire is fed into the bush *I*, with the carriage ped at the end of the slides remote from the bending and the clamping screw *J* is tightened when the end of vire just reaches the axis of *S* after passing through *R*, ixed portion of the bending unit. The rotating portion set to zero (that is, in line with the unused wire) and the ing unit *G* is also clamped in the zero position (that is, the slot horizontal). The carriage *F* is then unclamped moved forward a distance corresponding to the first l length and re-clamped. The first bend is then made. usually found necessary to "overshoot" slightly as the tends to spring back a degree or two. If the handle is sed, the wire is stiff enough to force the unit *S* back until nstrained position is reached and the true angle produced be measured. With a very small amount of experience pending can be done rapidly and precisely.

ie disk and the carriage are now unclamped by loosening d *Q*; it is important that the screw *J* clamping the wire ie carriage should not be released at this point. By g the disk and the carriage slightly the bent wire can be d clear of the bending unit, which is then returned to zero position. The carriage is moved forward a distance esponding to the next bond length and the bent portion ie wire passes through the slot in the disk. The rotating *G* is then set to define the angle between the planes for irst and second bends and, when all the clamping screws been tightened again, the second bend is made. Succes- bends are made in exactly the same way. If the carriage hes the end of the slide before the portion of the model g made from one piece of wire is complete, the clamping w *J* is released just after a bend has been made so that wire is held by the bending unit, and the carriage is ed back a known distance and *J* clamped again. More ls can then be made as before.

'henever any difficulty arises because the model bends on itself and tends to foul parts of the jig, it is best to he wire and make the model in smaller sections which can be joined by the second jig described in the next section.

3. BRAZING JIG

1 *Principle.* The brazing jig is a device for holding parts of a model in the correct relative orientation during ing. This might appear to be a very simple matter, but culties arise for two reasons. First, provision must be e for joining large sections of models and the clamps t be designed so that they hold the two wires to be joined firmly without fouling the rest of the model; secondly, necessary to control not only the bond angles at the but also the angles between the planes of the bends on r side of the join and the plane of the join.

is not easy to provide clamps for more than two wires with the jigs described it has been found best to construct - and four-bond junctions from only two pieces of wire. For example, a tetrahedral junction would be made from two pieces of wire, each bent at the middle with an angle of 109°, brazed together at the bends in the correct orientation.

Fig. 4 illustrates the basic movements required in order to make a three-bond junction between the two units shown in Fig. 4(*a*). The join is to be made at *C*. The bend at *C* is made in the first jig; the angle *BCD* is therefore already fixed. Two other bond angles are then involved, namely that between *DC* and *RC* and that between *BC* and *RC*. The two parts of the model must therefore be clamped with two degrees of rotational freedom. The simplest way of providing these is to permit rotation of the unit *ABCD* about a vertical axis through *C*, with *BC* and *CR* both held in a horizontal plane [Fig. 4(*b*)]. This rotation permits the angle between *BC* and *CR* to be fixed. Two of the three-bond angles are now fixed and the third can be set, without changing the first two, by rotation of the unit *ABCD* about *BC* as axis [Fig. 4(*c*)]. Direct correlation between the angle of rotation and the bond angle involves a considerable amount of calculation, and it has been found simpler to provide a special protractor for direct measurement of the third bond angle. A final rotation is still required to ensure that the plane of *QRC* is correctly related to the other part of the model. It is thus necessary for rotation of *PQRC* about *RC* as axis to be provided [Fig. 4(*d*)]. Provision for translation of *PQRC* to complete the joint is also necessary [Fig. 4(*e*)] (the separation in the figure is exaggerated for clarity).

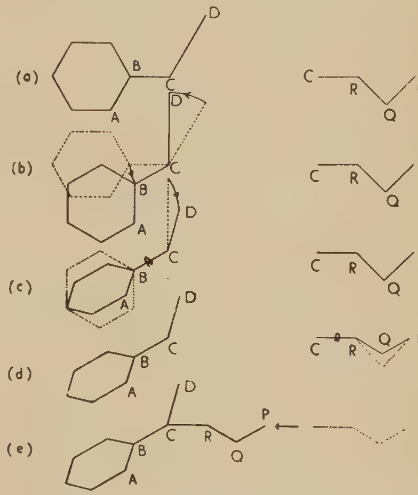


Fig. 4. Sequence of operations performed by the brazing jig

For a four-bond join—for example, if *ABCD* were to be joined at *C* to the part *R* of *PQRC*—the same set of three movements would be sufficient for setting the bond angles, since the plane *CRQ* would have already been set at the correct angle to *RQP* in the first jig.

3.2 *Construction.* Fig. 5 shows the form of the jig. It consists of two almost identical units *E* and *F*. The left-hand unit *E* is fixed to the baseboard by a pivot permitting rotation of the whole unit in a horizontal plane, thus providing the movement illustrated in Fig. 4(*b*). The angle of rotation can be read on a scale *H* and a clamping screw is provided to prevent rotation during brazing operations. The clamp arms are free to rotate about horizontal axes on bearings at J_E, J_F, providing the movements illustrated by Figs 4(*c*) and (*d*). Scales at *K*, *K′* permit the angles of rotation to be measured and clamping knobs *L*, *L′* prevent rotation during brazing. The cranked arms *M*, *M′* are made of $\frac{3}{8}$ in. diameter × $\frac{1}{16}$ in.

wall diameter brass tubing and are shaped to interfere as little as possible with the parts of the model already made. The clamps N, N' consist of slotted brass cylinders, tapered slightly to permit close approach to each other; the parts of the model are held in place by hooks on the ends of screwed rods passing down the arms to knurled nuts V. The screws U, U' permit precise adjustment of the length of the clamp arms to bring the wire on to the axis of rotation of J_E or J_F. The right-hand unit F is fixed to the baseboard by means of a wing nut and bolt, the holes in the base of the clamp and in the baseboard being slots arranged at right angles to each other so that the translational movements illustrated in Fig. 4(*e*) may be made and to facilitate removal of the finished models. Terminals W, W' are provided on the two cranked arms to permit connexion to the arc welding machine, the use of which is described in the next section.

The special protractor designed for measuring the third bond angle mentioned in Section 3.1 is illustrated in Fig. 6. Slots in the protractor rest on one of the wires and permit rotation of the protractor about this wire as axis until the scale touches the other wire involved. The bond angle may then be read directly. It has been found convenient to leave the wire CD longer than necessary for the bond until the joint is complete.

A further auxiliary unit that is found to be necessary is a "height bar." This is simply a small stand, which can be placed anywhere on the baseboard, carrying at its upper end a horizontal bar adjusted to be the same height from the baseboard as the horizontal rotation axes of the clamping units. The use of this bar is described in the next section.

3.3. *Use.* The sequence of operations to be followed in making the joint illustrated in Fig. 4(*a–e*) is as follows. First, section $ABCD$ of the model is clamped in the left-hand unit E (Fig. 5), the clamp being attached to the portion BC, with BC lying along the axis of the bearing J_E. For convenience the plane BCD is usually made horizontal when the plane of the cranked arm is vertical (in Fig. 5, BCD has been twisted out of this plane for the sake of clarity in the drawing). Section $PQRC$ is now clamped in the right-hand unit F, the clamp being attached along RC with RC lying along the axis of the bearing J_F. At this stage it is convenient to keep the unit F as far away from E as the adjustment provided by the wing nut will permit. In clamping the sections of the model, the end C of $PQRC$ is placed on the vertical axis of rotation of E, and the point C of $ABCD$ is kept a little to the left of this axis so that there is a gap of a millimetre or so between the two sections. Unit E is now rotated until the second angle BCR, read by means of the scale H, is correctly set.

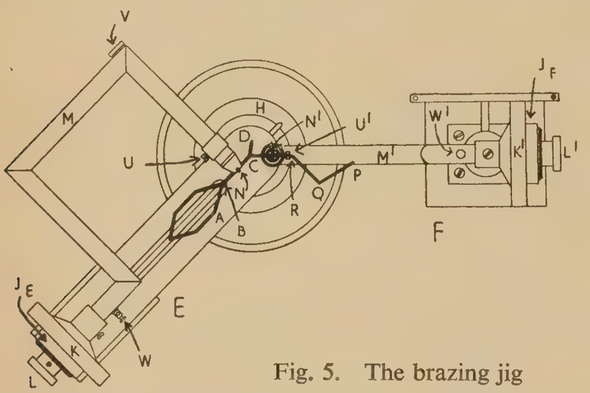
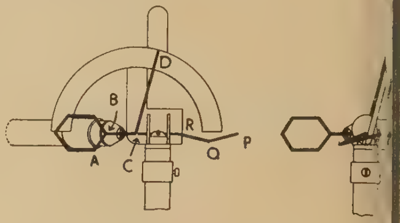


Fig. 5. The brazing jig

The third-angle protractor unit (Fig. 6) is now slipped on to the wire RC and rotated to touch CD; $ABCD$ is ro about BC until the angle RCD is correct and unit prevented from further rotation by tightening the kno By means of the height bar, placed somewhere near Q rotation of $PQRC$ about RC, the bond RQ is placed horizontal plane, i.e. the plane BCR, and the reading o scale K' is taken. Further rotation of $PQRC$ measure K' can then be made to give the plane QRC its co inclination to the plane BCR. Finally, unit F is moved b to close up the gap between the two sections to be joine all clamping screws are tightened.

Fig. 6. The third-angle protractor (not to scale)



The joint can be made in the usual way by means of a pipe flame, but the authors have found that a very sma welding unit used in conjunction with Easiflo hard solde flux (by Johnson, Matthey and Co. Ltd.) gives strong joints. Connexions from the welding unit are made t terminals on E and F and to the welding electrode—a ca rod. Flux, mixed with water to a stiff paste, is applied t wires and the point of contact touched with the elect In a few seconds the wires glow cherry-red, a small am of Easiflo silver solder is then applied and the joint all to cool before releasing the clamps. Finally the bond may be cut to length.

4. EXAMPLE

The model, mentioned in the Introduction and illust in Fig. 1, was made to test the jigs on a fairly compli object. It was made from eight separate lengths of Of these, three had five or more bends and the rem were short straight lengths or had only one bend.

The model took about two hours to make—largely be the best sequence of operations was being worked out a same time and because of lack of experience in dividin the work between the two jigs. (This excludes time tak computing certain angles between planes which are specifically given in the paper.)

ACKNOWLEDGEMENTS

Our thanks are due to Prof. H. Lipson and to va colleagues in the department for helpful discussions, and to Mr. A. D. Allen for preparing the photograph of F

REFERENCES

(1) Crystal Struct. Model Panel. *J. Sci. Instrum.*, **24**, p (1947).

(2) Lipson, H., and Cochran, W. *The Crystalline* Vol. III, p. 114 (London: Bell and Sons, 1953).

(3) Hughes, J. W., Phillips, D. C., Rogers, D., Wilson, A. J. C. *Acta Cryst.*, **2**, p. 240 (1949).

(4) Low, B. W., and Waldram, J. M. *J. Sci. Instrum.* p. 311 (1949).

(5) Hughes, W., and Taylor, C. A. *J. Sci. Instrum.* p. 105 (1953).

(6) Crowfoot, D., Bunn, C. W., Rogers-Low, B. W., Turner-Jones, A. *The X-ray Crystallographic In gation of the Structure of Penicillin* (Oxford: University Press, 1949).

Laboratory and workshop notes

h sensitivity d.c. null indicator with automatic reduction of sensitivity for large inputs

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te first received 24 *June, and in final form* 2 *December,* 1957]

olution of certain problems by the resistance network gue method requires the measurement of a set of d.c. ges ranging from about 1 mV to several hundred mV, g source resistances of from a few ohms up to about Ω, to an accuracy of ±10 μV. The bridge method of urement is convenient for this purpose and, for ease and ity of operation, the null indicator employed should the following attributes:

Adequate sensitivity and zero stability.

Constant voltage sensitivity regardless of the value of source resistance.

Automatic sensitivity control so that the instrument remains in range and gives an indication as to the direction in which the null lies when far from balance, thus relieving the operator of the need for continually adjusting a manual sensitivity control to obtain an on-scale reading.

Protection against damage due to accidental overloads such as can easily occur when searching for a null on a decade potentiometer of the type normally used as the measuring arms of the bridge.

e requirements apply generally to null indicators for d.c. e measurements which cover large voltage and source ance ranges and, on this basis, the instrument to be ibed was constructed.

galvanometer amplifier provides the simplest means of ning the desired sensitivity and zero stability and is fore taken as the basis of the design, improvements made to meet the requirements detailed above.

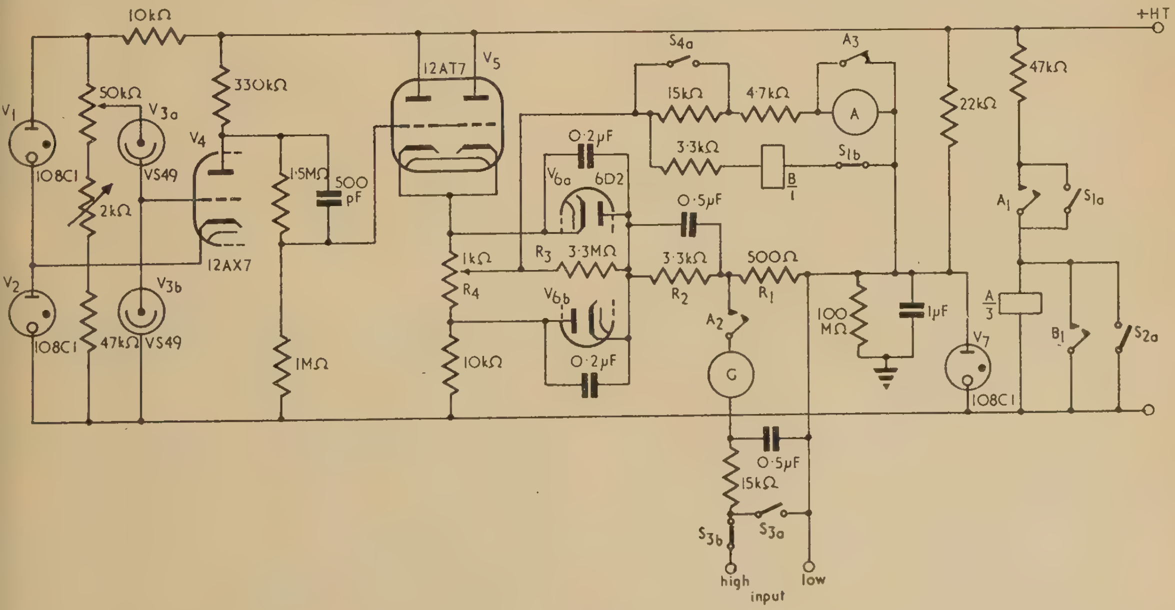
Referring to the circuit diagram, a double photo-electric cell V_{3A} and V_{3B}, in conjunction with a 6 W lamp and a reflecting galvanometer, generates the input signal for a single-stage thermionic valve amplifier V_4, and a cathode follower output stage V_5. Overall negative voltage feed-back from the output stage to the galvanometer input stabilizes the zero and increases the input resistance, so that the instrument has constant voltage sensitivity when connected to source resistances of up to 100 kΩ. For inputs which give up to plus or minus half full-scale deflexion on the centre zero output meter, the overall voltage gain is approximately:

$$A_1 = (R_1 + R_2 + R_3)/R_1$$

Under these conditions, diodes V_{6A} and V_{6B} are held non-conducting by the bias developed across resistance R_4 due to the cathode current of V_5, but for greater inputs the bias applied to either V_{6A} or V_{6B} is cancelled by the drop across resistance R_3, since until either diode conducts this drop is proportional to the signal whereas the drop across R_4 is practically independent of the signal. The polarity of the input voltage determines which diode conducts, but in either case the gain is reduced to approximately:

$$A_2 = (R_1 + R_2 + R_0)/R_1$$

where R_0 is the forward resistance of one of the diodes. The output meter deflexion, for which the sensitivity is reduced, may, of course, be set at any suitable value for the problem in hand by choice of the hold-off bias resistor R_4. In the circuit shown, A_1 and A_2 are chosen to give sensitivities of 30 μV/mm (input μV/mm output meter deflexion) and 10 mV/mm respectively (i.e. half full-scale deflexion corresponds to ±750 μV input and full-scale deflexion to ±0·5 V input), but these may also be set to suit the range of voltages to be measured by changing the ratios or values of resistances R_1 and R_2. Relays $A/3$ and $B/2$ perform the functions of open-circuiting the galvanometer movement and short-circuiting the output meter when an input which would give more than full-scale deflexion on the output meter is applied,



Circuit of the null indicator

or if the h.t. or mains supply fails. Four push button switches, S_1 to S_4, respectively, reset the relays, trip the relays for setting-up purposes, short the input for zero setting, and increase the sensitivity by a factor of four. Short-term zero offset can be up to ±20 μV (0·6 mm output meter deflexion) referred to the input, due mainly to mechanical disturbance of the galvanometer, and the long-term offset is such as to produce no readable deflexion on the output meter over the course of a day. A simple neon stabilizer supplies h.t. to the photo-electric cell; the remainder of the supplies are unstabilized.

The complete instrument comprises two units, one of which houses the lamp, galvanometer movement and photo-electric cell, and the other the amplifier and power supply. To keep the former unit reasonably compact and portable, a galvanometer to photo-electric cell distance of 20 cm is used, and the overall dimensions of the case, a heavy gauge sheet steel box, are 14 × 5 × 5 in. Although no shock absorbing mountings are used, external vibrations are not unduly troublesome providing the unit is placed on a firm surface.

Some factors influencing the optimum design of cascade image intensifiers

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[*Note received* 31 *July*, 1957]

It is now well known that the maximum light gain realizable in a simple photo-electronic image intensifier is of the order of a hundred.(1) For applications demanding much higher gains several stages of intensification will be needed and these lead to some new design problems. While it is generally true in principle that the overall gain increases with the number of stages, there is always a practical limit to the total accelerating potential that can be maintained with any stability across a given size of image tube. As the light gain per stage falls with increasing subdivision of the tube, there generally exists a subdivision into stages which is optimum. In the following we shall concern ourselves only with the question of light gain and examine the variation of the overall gain under various conditions.

It will be assumed that all the intensifier stages are identical, that they have 1 : 1 magnification and are contiguous, so that the luminescent screen of one stage is very close to the photo-cathode of the next. The stages consist of an antimony : caesium photo-emissive surface, which has the highest* quantum sensitivity,(2) some accelerating electrodes and an aluminium backed luminescent screen of zinc sulphide : silver. This again is the most efficient luminescent material under electron excitation known at present.(3) The electrons are focused by an external magnetic field, so that 1 : 1 magnification can be maintained as the accelerating potential is varied.

The zinc sulphide : silver phosphor has a blue emission with a mean photon energy of ∼2·6 eV.(1) Its intrinsic luminescence efficiency has been investigated by Bril and Klasens(3) for various electron energies down to 2·5 keV. It is found to have a rather flat maximum of 24% at 30 keV and to fall rapidly below about 10 keV. However, due to the isotropic emission and reflexion by the phosphor, about 30% of the luminescent light is emitted in the for direction. This situation is to some extent remedied b application of a thin aluminium backing. There i optimum but not very critical film thickness which yiel enhanced forward emission ×2·2 with willemite, for elec of 10 keV or higher energies.(3) We shall assume th similar figure holds for the zinc sulphide : silver phosph

Below 10 keV the situation is a little more compli and no direct measurements appear to have been n There is still an optimum film thickness for each voltage the realizable enhancement factor will be less than 2·2. factor can be computed by using the well-known Thom Whiddington law for the energy loss of electrons in pa through a thickness of matter x,

$$E_{in}^2 - E_{out}^2 = kx$$

together with the Lenard formula for the number of elec penetrating through x,

$$n_{out} = n_{in} \exp(-kx/E_{in}^2)$$

The constant k is given by Longini(4) to be

$$\sim 5 \times 10^5 \text{ (keV)}^2/\text{g/cm}^{-2}.$$

From equations (1) and (2) and the results of Bril Klasens(3) on the variation of luminescence efficiency electron energy, the optimum enhancement factor has calculated and the results are shown by the broken cur Fig. 1. Very little enhancement appears to be possible b about 2·5 keV, but the validity of formulae (1) and is rather questionable at these low energies. From curve and the results of Bril and Klasens the maxin realizable luminescent yield in photons per electron various energies has been computed. This leads to the curve shown in Fig. 1.

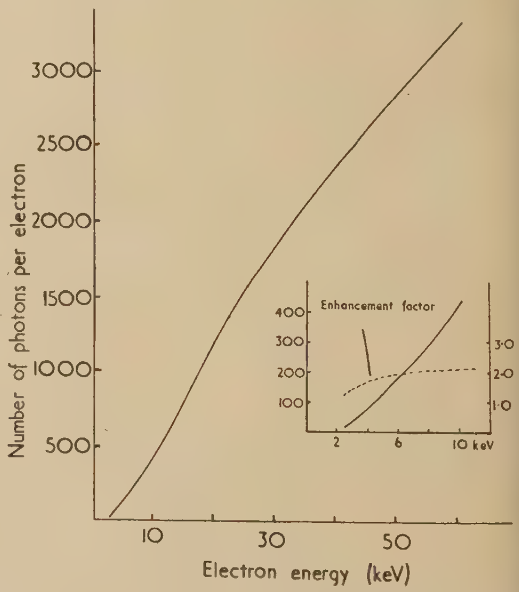

Fig. 1. Maximum luminescent yield from a ZnS : screen as a function of electron energy

Finally when these figures are combined with the quar sensitivity of the photo-cathode to the blue emission of zinc sulphide : silver phosphor, which has been shown t ∼15½%,(1) we obtain the maximum realizable gain

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* A more sensitive photo-emissive surface has recently been described by Sommer, A. H., *Rev. Sci. Instrum.*, **26**, p. 725 (1957).

$g(V)$, as a function of electron energy. If the total rating potential is V_0 and there are n stages, then V_0/n. The maximum overall light gain G_{max} is then by:

$$G_{max} = [g(V_0/n)]^n \qquad (3)$$

this point some serious practical limitations have to be . In practice, the maximum gain figures $g(V)$ have been attained and, indeed, the figures reported so far n order of magnitude lower. The situation reflects nsiderable experimental difficulties of forming efficient ony: caesium surfaces and efficient luminescent screens f achieving stable operation free from excessive back-d effects. These difficulties are increased in a cascade tube.

shall take note of these limitations of present-day ques by introducing a factor $\beta (0 < \beta < 1)$, such that perimentally realizable gain is represented by $\beta g(V)$. l be assumed that any established technique leads to a ntially constant β. Equation (3) must now be replaced

$$G = [\beta g(V_0/n)]^n \qquad (4)$$

typical values of β and V_0, this function G normally through a maximum as n increasing from 1, so that exists an optimum number of stages. Thus, on taking thms and differentiating, we find:

$$\frac{1}{G}\frac{dG}{dn} = \log\,[\beta g(V_0/n)] - \left(\frac{V_0}{n}\right)\frac{g'(V_0/n)}{g(V_0/n)}$$

t the position of the maximum is given by:

$$\log \beta g(V) = \frac{Vg'(V)}{g(V)}$$

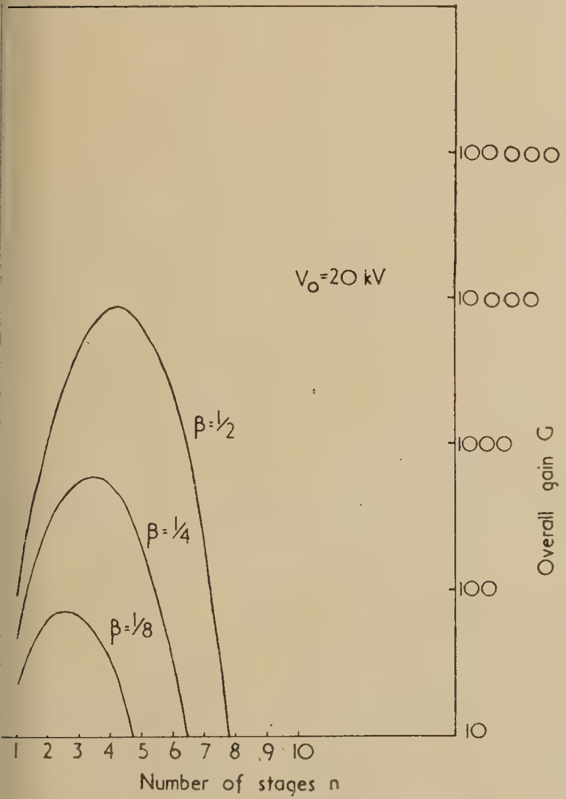

Fig. 2. The variation of overall light gains with increasing subdivision into stages

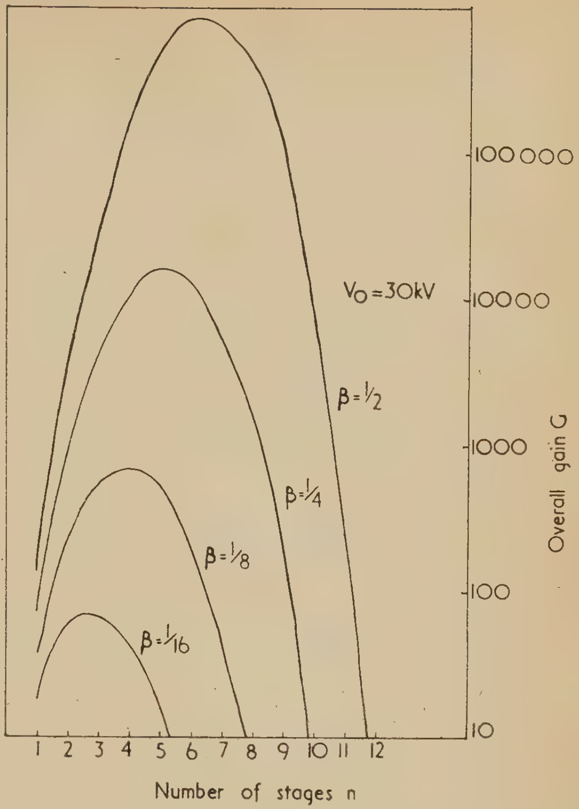

Fig. 3. The variation of overall light gains with increasing subdivision into stages

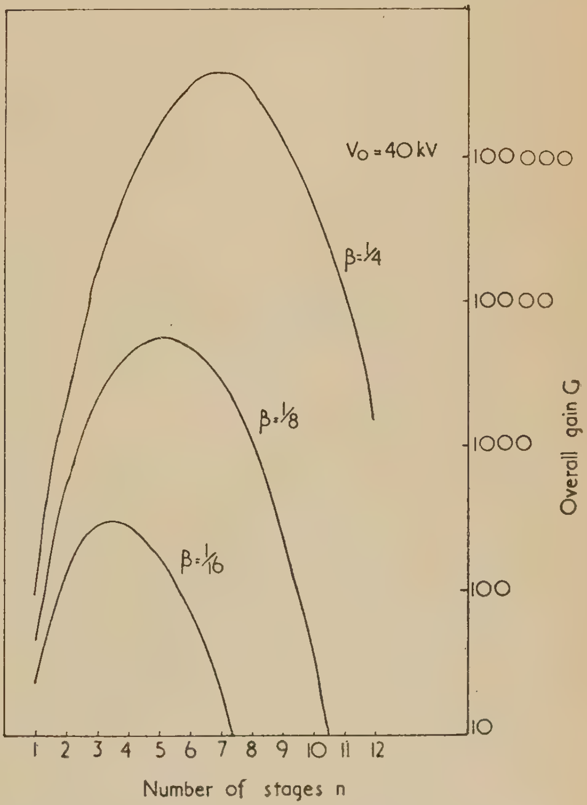

Fig. 4. The variation of overall light gains with increasing subdivision into stages

or
$$\beta g(V) = \exp\left[Vg'(V)/g(V)\right] \tag{5}$$

This has a particularly simple solution if we make a rough linear approximation to the function $g(V)$ shown in Fig. 1, in the region 4 to 8 kV. Thus, on writing:

$$g(V) = mV - c \tag{6}$$

with $c \sim 23$, we obtain from (5),

$$\beta g(V) = \exp\left[1 + c/g(V)\right] \tag{7}$$

This equation yields a definite value $g(V)$ for each β *which is independent of* V_0. From Fig. 1 this can then be converted into an optimum potential V per stage. Some solutions are summarized in the following table.

Some solutions of equation (7)

β	*maximum* $g(V)$	*maximum* $\beta g(V)$	*optimum* V *in kV*
1	14·0	14·0	4·3
$\frac{1}{2}$	18·6	9·3	4·9
$\frac{1}{4}$	26·2	6·5	5·8
$\frac{1}{8}$	39·3	4·9	7·4
$\frac{1}{16}$	62·8	3·9	9·9

The optimum number of stages n_{opt} follows immediately from the table since $n_{opt} = V_0/V_{opt}$. This number will not, in general, be integral and the nearest integer will have to be chosen in practice.

In order to see how critical these optimum values are, the gain G has been computed from equation (4) over a whole range of values of the parameters β, V_0 and n. The results are shown in Figs. 2, 3 and 4. As will be seen, the maximum is broader for the higher potentials V_0. Thus, with $V_0 = 40$ kV and $\beta = \frac{1}{8}$, the optimum stage number is 5. But four stages yield almost as much gain.

The curves also give n_{opt} and hence V_{opt} directly and us to check the accuracy of the results obtained fro approximate equation (7). As the following table show agreement is fairly good.

Showing the accuracy of the approximate solutions

	$\beta = 1/2$	$\beta = 1/4$	$\beta = 1/8$	β
Optimum V at $V_0 = 20$ kV	4·8	5·9	7·7	—
Optimum V at $V_0 = 30$ kV	4·8	5·9	7·4	1
Optimum V at $V_0 = 40$ kV	—	5·7	7·7	1
Optimum V from equation (7)	4·9	5·8	7·4	9

Throughout the foregoing it has been assumed tha stages are identical. However, it is not difficult to show in a voltage range in which $g(V)$ is approximately linear as it is above, this subdivision into equal stages is, in fac optimum one.

It appears therefore that there exists an opti accelerating potential per stage, which is determined on the conversion efficiencies of the photocathode and fluorescent screen. With gradually improving technic will be possible to realize higher gains, but the foreg results should help to achieve the best performance wit established technique.

REFERENCES

(1) MANDEL, L. *J. Sci. Instrum.*, **32**, p. 405 (1955).
(2) BURTON, J. A. See ZWORYKIN and RAMBERG, *Electricity*, 1st ed., p. 59 (London: Chapman and Ltd., 1949).
(3) BRIL, A., and KLASENS, H. A. *Philips Res. Rep.*, **7**, p (1952).
4) LONGINI, R. L. *J. Opt. Soc. Amer.*, **39**, p. 877 (194

NOTES AND NEWS

Correspondence

A double layer-line screen for Weissenberg photography

Since the appearance of my Note on p. 180 of the May issue of this *Journal*, I have learned that the essential ideas have been adequately discussed by Stadler$^{(1)}$ and Ruston.$^{(2)}$ I regret the omission of any reference to their work.

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National Research Council,
Ottawa, Canada.

A. W. HANSON
[3 June, 1958]

(1) STADLER, H. P. *Acta Cryst.*, **3**, p. 262 (1950).
(2) RUSTON, W. R. *Acta Cryst.*, **4**, p. 473 (1951)

A valve for the grease-free manipulation of mercury

Dr. G. A. Bottomley in a Note in this *Journal** stresses the importance of ensuring that the tapered glass seating is perfectly circular in cross-section, so that when the steel ball is ground into it an even band of grinding is produced in one plane. It is difficulty to obtain a circular seating by freehand methods even if the tubing is carefully selected.

When constructing ball valves a method of overcoming this difficulty is to mould the seating around a steel former. The method was briefly outlined in an account which I wrote† of a symposium on glassworking held by the Ministr Supply on 2nd December, 1954. The details of the me are as follows:

A mild steel rod is selected which is an easy fit in 12 mm diameter glass tube, and the end of the rod is tu down to a point with an included angle of approxim 90°. The tapered portion should be given a smooth f by taking a fine final cut on the lathe. This end should be cut off to a length of approximately 40 mm, any b raised by the cutting removed, and the metal degreased trichlorethylene. A piece of the 12 mm diameter tube less than 100 mm long should be joined to the capillary and the shoulder between them drawn down to an a slightly greater than 90°. When this is cold the piec metal should be carefully pushed inside, point first, a piece of tubing approximately 8 mm diameter and 1·5 wall thickness should be joined on the open end. capillary should be sealed off, or closed temporarily wi policeman and the whole thing evacuated through the 8 end. A rotary pump may be used but a good water pum sufficient. The 8 mm tube is sealed off with a flame allowed to cool. The tube is cautiously tapped until metal former is in such close contact with the tapered that the point enters the bore of the capillary. The tap portion is heated, carefully at first to allow the glass l to reach the same temperature. A small gas-air flame ld then be directed on to the tapered portion of the glass it softens slightly and collapses down on to the metal, being taken not to melt the capillary. The glass should moved from the flame and as soon as it has become it can be tilted so that when tapped the metal will slide to the opposite end of the tube. When the metal has cooled air may be let in cautiously, the tube cut open and the metal removed. If possible the glass should be annealed in an oven before the grinding is carried out.

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* BOTTOMLEY, G. A. *J. Sci. Instrum.*, **34**, p. 369 (1957).
† FROST, J. A. *Laboratory Practice*, p. 30 (1955).

Department of Chemistry,
The University,
Reading.

J. A. Frost
[13 March, 1958]

New book

umentation in testing aircraft. By C. N. Jaques. (London: Chapman and Hall Ltd., 1957.) Pp. xi + 291. Price 45*s*.

rapid and fundamental advances in the field of aircraft n during the past two decades have naturally resulted imilar development pattern in the instrumentation needed aluate the performance and behaviour of new aircraft. Jaques has made the first attempt in this country to y in some detail the state of this particular art, and it be reported with disappointment that the book has untered a pitfall not unknown to the aircraft industry—of taking so long in the design and production stages availability for service becomes coincident with lescence.

is "dating" is significant because less than one quarter e book is concerned with basic principles and general ssion, the remainder being occupied with more or less led descriptions of particular items of flight and ground umentation, most of which were in proven use by 1950– A fair proportion of these, relating to aircraft manoeuvres, are based on the Desynn repeater system normally associated with the photo-recording of dial indicators. Not until Chapter 19 is the reader warned that this system is only suited to frequencies up to about 2 c/s. Such instruments are still in limited use, mainly in the larger and slower aircraft, but a major share of flight instrumentation during the last five years or more has been carried by galvanometer trace recorders and potentiometric transducers, usually without amplification. Such techniques receive only slight attention in this monograph, and there is no mention whatever of tape recording or radio telemetry, both of which are now sufficiently established in forms suitable for aircraft use that they must be seriously considered by flight test engineers currently planning an advanced installation.

Fortunately the requirements for ground testing have not changed so rapidly, and the working descriptions of several large multi-channel recorders for strain-gauge surveys, high-frequency vibrations, blast measurements, etc., will be of interest and use to workers in these fields, both inside and outside the aircraft industry.

C. M. Britland

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ucts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

netically sealed silver–zinc accumulators. Venner Accumulators Ltd., Kingston By-Pass, New Malden, Surrey.

HT125 cell has a nominal capacity of 125 mAh and an f. of 1·5 V; it is stated to be suitable for discharge ents from 10 to 500 mA. This range covers many sistor applications and current requirements too large to net by small dry cells. The cells are available as batteries aining any number of cells, in strips from 1 to 10, nged in any desired form and potted in resin. Charging be carried out either by constant current or constant ntial systems. No other maintenance is required. A le cell weighs $\frac{1}{3}$ oz and measures $1\frac{1}{8} \times 1\frac{1}{4} \times \frac{9}{32}$ in.

mium sulphide photoelectric cell. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

new cell incorporates a photo-sensitive element of nium sulphide, and has a high sensitivity: it is claimed e some 20 000 times more sensitive than the conventional to-emissive cell.

ven from weak sources of light it is said to produce sufficient current to operate a large relay direct, without the need for intermediate amplification. Furthermore, the cell will produce the current necessary to operate a relay with only a very low applied voltage.

The cadmium sulphide cells will be mounted on standard valve bases identical with those of the present range of conventional cells by this firm. Thus, when existing equipments are modified, special head mountings or probes designed for specific installations can be retained.

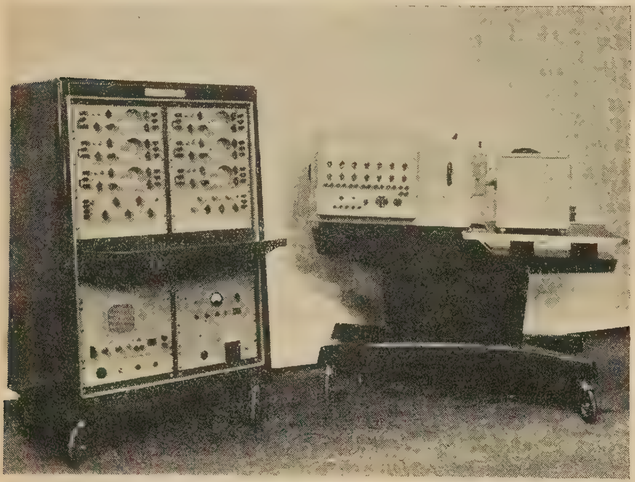
The cadmium sulphide cell can replace the conventional photo-emissive cells in the majority of devices designed to perform "on-off" switching operations at speeds up to about 50 c/s. Its inherent ruggedness makes it particularly suitable for industrial use, and being non-polar it will operate from both a.c. and d.c. supplies. It offers particular advantage in flame-failure detectors for oil-fired burners since its spectral response is greatest in the yellow/red region.

Typical performance figures for this cadmium sulphide cell with a photocathode of 1·8 cm^2 effective area are claimed to be as follows:

From an illumination of 5 ft-lamberts, with a colour temperature of 1500° K, the cell will produce approximately 20 mA of current for an applied voltage of 10 V. From the same illumination, but with a temperature of 2700° K, the current is approximately 6 mA. Within the limits of permissible power dissipation doubling the applied voltage gives a four-fold increase in current. Maximum dissipation is 1 W at 25° C and 200 mW at 75° C. Dark current is extremely low: with 300 V applied to the cell it is not greater than 2·5 μA at 25° C. Spectral response range is 4500 Å to 8000 Å, covering the entire visible spectrum and extending into the near infra-red, with maximum response in the yellow/red region.

Universal oscillograph. Southern Instruments Ltd., Frimley Road, Camberley, Surrey.

The type MUR universal oscillograph illustrated in the figure provides a multi-channel recording equipment of great flexibility. The 3 in. diameter recording tubes are separate from the main equipment, being housed in a cabinet to which the camera and optical system are fitted. Power supplies and driving voltages are supplied to a master distribution panel in this unit by means of flexible cables from an amplifier console. Within the recording unit, the tubes are mounted in adjustable clamps on a short steel column. This is fitted to a base sliding on rails and enables the tubes to be moved towards or away from the camera lens in a precise manner. Thus the operator can alter conditions so as to photograph as many of the tube faces as are needed. It is obviously possible to install a simple equipment in the first place and subsequently to add tubes and amplifiers to provide further channels as required. Two models are available, providing up to six and twelve channels respectively, with time marking.


Six channel oscillograph equipment

Cathode-ray storage tube for visual observation of transients. A. E. Cawkell, 6–8 Victory Arcade, Southall, Middlesex.

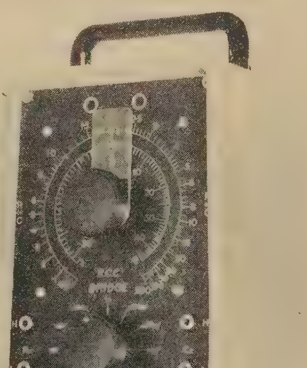
The Memotron storage tube contains two electron guns. One of these, known as the flood gun, produces low velocity electrons. The other, known as the writing gun, is similar to that in a normal tube and has *X* and *Y* deflector plates attached to it. Between the guns and the screen, which is coated with a normal P1 phosphor, are the third anode, a storage mesh electrode and an adjacent secondary electron collector. The storage mesh is coated on one side with a dielectric material. It is continuously sprayed with flood gun electrons but, in the "unwritten" condition, is at a suffi
negative potential to prevent the flood gun electrons pa
through to the viewing screen. To write a trace, the
of the writing gun is switched on. Electrons, deflected i
normal manner by applied *X* and *Y* deflector voltages, s
the storage mesh and cause secondary emission.
bombarded areas of the mesh therefore rise in potential
they assume the potential of the adjacent secondary emis
collector electrode; they are then transparent to the f
gun electrons which pass through and are accelerated o
the viewing screen by the potential applied to the third an
which is between the storage mesh and the screen. A
written on the storage mesh is therefore displayed on
screen until erased by lowering the potential of the secon
emission collector electrode.

The tube can be supplied in a unit which contains su
networks for the electrodes with suitable controls, a sw
for local or remote control of erasure, a press butto
erasure and a pulse generator for modulating the storag
collector electrodes to improve contrast. The resulting
can be combined with e.h.t. supply, amplifiers, scan genera
and other units to form a complete equipment to
individual requirements.

It is claimed that a non-recurrent transient will be st
provided the writing speed does not exceed 10^5 in./s
repetitive wave-forms, the storage action is cumulative
the writing speed is greater, depending on the duration
number of the repetitions. A resolution of 50 lines, i
claimed. It is possible to arrange for a transient to be m
to remain for an interval long enough for examinatio
then to be erased automatically. Alternatively, transi
may be displayed and stored one below the other,
making the effect of adjustments in the test conditi
immediately apparent. If the secondary emission colle
voltage is lowered ("erase") the device will function
normal cathode-ray tube.

Resistance and capacitance bridge. Nash and Thompson
Oakcroft Road, Chessington, Surrey.

This instrument is intended for the measurement of resist
and capacitance or for the comparison of resistors, capac
and inductors against known standards. It employs a Wh
stone bridge for resistance measurement and a de S


Resistance capacity bridge

for capacitance measurement. In both instances, the rement is made at mains frequency with an applied tial of 18 V. Both bridge circuits use a twin neon lamp to indicate the balance point. This consists of two neon lamps visible through circular apertures at the the panel. To obtain a reading, the balancing potentio- carrying the scale cursor is rotated in the direction of ghted neon lamps. As the cursor approaches the value component under test, this neon lamp dims and, at the ce point, goes out. On passing through this point, the neon lamp strikes. It is possible to pin-point the balance ting so that both neon lamps are extinguished or glowing ly. It is claimed that this device is far more sensitive asier to use than the usual "magic eye" type of indicator. otentiometer wire is cam corrected and has a guaranteed ity within 0·1%, permitting the use of a pre-printed The instrument covers the range 5 Ω–500 MΩ in 3 s, and the capacitance range 5 pF–500 μF in 3 ranges internal standards. Comparison with external standards r the range −30% to +45% within the limits 100 Ω–5 MΩ or 600 pF–30 μF or 0·3–15 000 H. The accuracy is of the order of 1%.

Non-destructive flash tester. Labgear Ltd., Willow Place, Cambridge.

The E 5117 tester is designed for the batch testing of components or other breakdown applications at voltages of 250, 500, 1000, 1500 and 2000 V a.c. Other test voltages up to 10 kV can be supplied to special order. These voltages are selected by a high grade ceramic switch controlled from the front panel. Indication of breakdown is observed on a moving-coil meter, the pointer of which is adjusted to a red mark on the dial before the circuit under test is connected. Evidence of breakdown is shown when the meter pointer falls below the red mark. Two heavily insulated terminals are provided on the front panel for attachment of a test jig for the components under test. Because of the minute current flowing under fault conditions, a component or circuit is claimed to be capable of being tested to breakdown point and beyond without damage.

Notes and comments

ture of instruments and instrumentation

symposium on the literature of instruments and instru- ation organized by the Information Department of the h Scientific Instrument Research Association was held ir library on 6 May last.

e twenty people who participated, by invitation, included rs of journals devoted to instruments, and of abstracting als; authors of books on instruments, scientists with a l knowledge of instrument literature, together with members of the staff of the Research Association. papers, dealing between them with the quantity, ty, distribution and use of the literature of the subject presented and discussed.

ch of the data given in the papers served mainly to rm and give some precision to existing general impres- : they confirmed, for instance, that while there were vely few books on instruments, there was an abundance riodical literature, which included 54 journals devoted arily to instruments and automatic control. Half of had started publication since 1954, and just over half in the English language.

e total number of separate articles about instruments shed annually was estimated to be of the order of 10 000. critical reviews were badly needed; nevertheless existing acting services, taken together, did enable a scientist to reasonably up-to-date with developments reported in ished papers, but not with semi-published report material. us estimates indicated that the latter accounted for a antial proportion—between 6% and 11%—of the total ber of documents on instruments; but it was difficult to learn of their existence and to procure copies, and quality was very uneven. It was generally agreed that t literature was a weak link in the chain of communi- n. Another weakness arose from the difficulties pre- d to abstractors and indexers by the tendency for short seful information about an instrument or apparatus to st in the body or at the tail of articles not primarily erned with the instrument, or in books which were m catalogued chapter by chapter.

The growing volume of literature on instruments—now estimated to amount to between 15 000 and 25 000 items a year—made more necessary than ever good classification schemes on which rapid searching systems could be based. Valuable research in this field is being done by the Office of Basic Instrumentation of the National Bureau of Standards in the U.S.A., whose Director had contributed some useful statistical data to the symposium.

Two papers dealt with specialized but important types of instrument publication: manufacturers' literature, and buyers' guides and directories. A survey showed that in the first the frequent absence of precise data on, for instance, accuracy, sensitivity and speed of response and the still more frequent absence of a date of publication, gave the user unnecessary trouble. The publication since the war of several specialized buyers' guides to instruments had been most helpful, but it was still necessary to use two or more in conjunction to provide adequate coverage.

No formal proposals arose from the discussions, but there was a concensus of opinion that more good books on instruments were needed, and more critical reviews, and that semi-published report literature needed to be critically surveyed and its value assessed.

A report containing the papers and appendixes in full, and summaries of the discussions, is being prepared by the Research Association.

International conference on the peaceful uses of atomic energy

The list of 2500 scientific papers to be presented before the 1958 International Conference on the Peaceful Uses of Atomic Energy, 1–13 September, 1958, is being made available by the Document Service of The Chronicle of United Nations Activities.

The subject-matter ranges through all the aspects of the peaceful uses of atomic energy, including the production and control of thermo-nuclear power; advances in reactor technology; extraction and refining of nuclear materials; effects and control of radiation; uses of isotopes in industry, agriculture, and medicine; and many other research developments from the major laboratories of the world. Copies of the list, free of charge, may be obtained from the Atomic Energy Document Service, The Chronicle of United Nations Activities, 234 West 26 Street, New York 1, N.Y., U.S.A.

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: H. Adam, J. F. Archard, J. J. Benbow, M. M. Bluhm, A. W. Crook, J. Darbyshire, L. R. B. Elton, J. H. Jaffe, E. W. Kellerman, C. N. W. Litting, D. McGill, E. G. Steward, A. N. Stroh.

Associates: H. S. Adams, G. J. Ames, M. I. Andrews, R. G. Angus, D. G. Baldwin, B. Barber, D. A. Calder, J. A. Carruthers, L. G. S. Clark, P. R. Cloud, J. K. Easlea, R. H. Haynes, D. G. Holloway, H. M. McGeachin, D. H. Morton, A. P. Rouse, M. Seal, D. G. Singleton, M. J. Smith, W. S. Symes, R. Thorburn, D. R. Tibbetts, A. H. Truelove, C. Turner, C. H. Ward, R. West, R. W. Whitworth.

Thirty-five Graduates, one hundred and two Students and five Subscribers were also elected.

Exhibition of scientific instruments and apparatus

The Australian Branch of The Institute of Physics will hold its sixth annual exhibition of scientific instruments and apparatus in the Physics Department of the University of Adelaide from 19–22 August, 1958.

The exhibition will coincide with the Adelaide Congress of the Australian and New Zealand Association for the Advancement of Science which will also be held at the University.

Instrument enquiries service

In order to help prospective instrument users to discover the sources of supply and particulars of the type of instrument best suited to their needs, the Scientific Instrument Manufacturers' Association of Great Britain Ltd. have established a technical enquiry service in collaboration with the British Scientific Instrument Research Association. It is hoped that, through this service, enquirers may be able to obtain the most accurate and up-to-date information on all products manufactured by the members of the Association. The telephone number to which enquiries should be directed is IMPerial 6000.

Wear

The aim of a new "international" Journal entitled *Wear*, which commenced publication in August 1957, is to report on basic research on friction, lubrication, and wear and the application of the results to industry. The Editor is Dr. G. Salomon of Delft and he is supported by international editorial and advisory boards. Papers and review articles are published in English, French or German, and are supplemented by a section containing book reviews, abstrac papers appearing elsewhere, and brief reports on cu events.

Wear will have six issues to the volume of about 500 and is published by Elsevier Publishing Co. of Amste at £5 7*s*. 6*d*. or $15 per volume. Once again it is our plea to wish success to yet another contemporary.

The Geophysical Journal

The first issue of *The Geophysical Journal* was publish March this year. This is a journal intended for the p cation of papers on research and progress in geoph and related subjects. It incorporates the earlier *Geophy Supplement* to the *Monthly Notices of the Royal A nomical Society*; by widening its scope to include, in add to original papers, such matters as reports of geophy discussions, short notes and letters and book reviews, hoped to increase its circulation throughout the large of exploration geophysicists.

There is no limit to the range of geophysical sub which the journal covers. Contributions to the first nu come from Australia, Canada, the U.K., the U.S.A. an U.S.S.R. and the papers cover such varied subjects a use of hydrogen bomb explosions for seismological purp the application of geomagnetic measurements to stud ionic density in the outer atmosphere; polar wandering theory underlying calibration of travimeters by compa with pendulums, and a review of the recent Toronto U.G conference. Of more immediate practical nature is a p on a seismic refraction survey off the north coast of Corn At the end of the journal there is a series of Russian t lations of summaries of the original papers.

The *Journal* is published quarterly by The Royal Astr mical Society, Burlington House, London, W.1. The an subscription is £3 (U.S.A. $9.)

British Journal of Applied Physics

Contents of the July issue

SPECIAL ARTICLE

Recent developments in electron microscopy. By V. E. Cosslett.

ORIGINAL CONTRIBUTIONS

Papers

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The analysis of particle counts by the spray-drop method. By K. I. Willi and W. B. Taylor.

The chromatic field aberrations and their correction in a three-lens ref electron microscope. By D. H. Page.

Solid angle corrections to single scattering. By F. F. Heymann and P. Kalmus.

New techniques for the study of bitter figures. By D. J. Craik and P. M. Gr

The photoelastic technique for strain measurement on flat aluminium surfaces. By H. Fessler and D. J. Haines.

Stability and convergence limitations on the use of analogue computer resistance network analogues. By M. E. Fisher.

The performance of infra-red photoconductive cells. By D. H. Robert B. L. H. Wilson.

NOTES AND NEWS

Correspondence

A note on the calculation of second moments of nuclear magnetic reso absorption lines. From J. G. Powles.

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SPECIAL ARTICLE

Infra-red and microwave modulation using free carriers in semiconductors*

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A description of the classical Drude–Zener theory of the dielectric constant and conductivity of a conductor is given, with particular reference to germanium and other semiconductors. The degree of agreement between theory and experiment is indicated. Methods whereby the conductivity of a semiconductor may be modulated and the application of these techniques to the study of the optical and microwave properties of semiconductors are described.

1. INTRODUCTION

e has been considerable interest in recent years in the cal properties of free carriers in semiconductors. This est probably arises from two main causes.

) Terms which may be neglected in metals or insulators can be made comparable in semiconductors, thus leading to more complicated and interesting phenomena, the study of which can give valuable fundamental information about the material.

i) The ability to change the number and mobility of the carriers either chemically (e.g. by adding impurities) or electrically (e.g. by carrier injection as in a transistor) allows a number of new microwave and infra-red techniques to be envisaged.

he present article will be concerned primarily with the nd of these aspects, with particular reference to ger- nium. A general review of the theory of the optical perties of free carriers in semiconductors will be given the degree of agreement between theory and experiment be indicated. The techniques whereby the carrier bility and density may be varied electrically will then be cribed, and some examples of the application of these niques will be given. It is hoped to show that the trical modulation of the optical properties of semicon- tors is a valuable, and by no means exhausted, tool in study of such materials.

THE DIELECTRIC CONSTANT AND THE CONDUCTIVITY OF A CONDUCTOR (THE DRUDE-ZENER THEORY)

he classical and quantum mechanical theories of the ectric constant and conductivity of a solid lead to essen- y similar results and are given in many textbooks (see, example, Seitz(1)). The present approach is classical and onalized M.K.S. units will be used throughout.

n general, the free carriers in a solid cannot follow an lied a.c. voltage exactly, but will tend to lag behind. nce the current due to the motion of the carriers will sist of two components, namely an in-phase current cribed by the a.c. conductivity, and a component 90° ind the voltage which contributes to the dielectric constant. magnitude of the current components is deduced from the equation of motion of a free carrier which may be written

$$m(dv/dt) + (m/\tau)v = q\,.\,E(t) \tag{1}$$

where m = the mass of the carrier, assumed to be single-valued but not necessarily equal to the free space mass, m_0

q = the electronic charge

$E(t)$ = the electric field applied = $E_0 \sin(\omega t)$

τ = the carrier relaxation time, i.e. the time between collisions

v = carrier drift velocity

In the presence of a magnetic field of flux density B, the right-hand side of equation (1) becomes

$$q[E(t) + v \times B]$$

Initially, however, we shall assume that $B = 0$ and introduce the effect of a magnetic field later.

In all real materials there is, in addition to the current carried by the free carriers, a displacement current due to the polarizability of the atoms or ions of the lattice. This component is purely capacitive and gives rise to a current which *leads* the field E by 90°. Hence the dielectric constant of the material is given by two terms 180° out-of-phase, i.e. of opposite sign. By convention, a lead of 90° is counted positive. The in-phase current, on the other hand, is due only to the free carriers. Hence the free carrier contribution is equivalent to an inductance and resistance in parallel, and the system as a whole is equivalent to a damped tuned circuit. Resonance effects (actually plasma resonance) may therefore be anticipated.

3. THE BASIC EQUATIONS

In the absence of a magnetic field, the dielectric constant and conductivity, deduced from equation (1) together with the field equations for an electromagnetic wave, are given by

$$\frac{\epsilon'}{\epsilon_0} = \underbrace{n^2}_{\text{lattice term}} - \underbrace{\left[\frac{\sigma_0}{\omega\epsilon_0}\cdot\frac{\omega\tau}{(1+\omega^2\tau^2)}\right]}_{\text{free carrier term}} \tag{2}$$

and $$\sigma/\omega\epsilon_0 = (\sigma_0/\omega\epsilon_0)[1/(1+\omega^2\tau^2)] \tag{3}$$

where $$\tau = m\mu/q \text{ and } \sigma_0 = Nq\mu = Nq^2\tau/m \tag{4}$$

The $\omega\epsilon_0$ is included in the denominator of both sides of equation (3) and ω not cancelled in equation (2) for reasons of mathematical symmetry with later equations.

Based on a lecture delivered to the Electronics Group of The itute of Physics, in London on 10 December, 1957.

The symbols in equations (2), (3) and (4) have the following interpretation:

ϵ'/ϵ_0 = dielectric constant of medium
ϵ_0 = permittivity of free space = $8{\cdot}854 \times 10^{-12}$ F m^{-1}
ω = angular frequency
n^2 = contribution to dielectric constant by the lattice
σ = conductivity (Ω^{-1}m^{-1})
σ_0 = conductivity at zero frequency
τ = carrier mean free time between collisions, of the order of 10^{-12} or 10^{-13} s in most materials
m = carrier effective mass (kg)
q = electronic charge (C)
μ = carrier mobility (m^{2}V^{-1}s^{-1})
N = carrier density (m^{-3})

4. OBSERVED QUANTITIES

In optics, the dielectric constant and the conductivity of a medium are rarely observed directly. The textbooks of optics give the observed quantities (e.g. reflectivity) in terms of the optical constants of the material n' (the phase constant) and k (the attenuation constant). The optical constants are related to the dielectric constant and conductivity by the equations

$$n'^2 = 1/2\{[(\epsilon'/\epsilon_0)^2 + (\sigma/\omega\epsilon_0)^2]^{\frac{1}{2}} + (\epsilon'/\epsilon_0)\} \qquad (5)$$

and

$$k^2 = 1/2\{[(\epsilon'/\epsilon_0)^2 + (\sigma/\omega\epsilon_0)^2)^{\frac{1}{2}} - (\epsilon'/\epsilon_0)\} \qquad (6)$$

Equations (5) and (6) are modified if the electromagnetic wave is bounded, as in a waveguide. The presence of the conducting walls changes the propagation velocity of the wave so their effect can be described as a modification of the dielectric constant. If the walls of the guide are assumed to be perfectly conducting, equations (5) and (6) are still valid if

$$[(\epsilon'/\epsilon_0) - (\lambda_0/\lambda_c)^2] \text{ is written for } [\epsilon'/\epsilon_0]$$

where λ_0 is the wavelength in free space and λ_c the cut-off wavelength of the guide. In general, this is a small correction for semiconductors, as ϵ'/ϵ_0 is large (about sixteen for germanium) and (λ_0/λ_c) is less than unity.

The most frequently measured optical properties are given in terms of n' and k and some of the more important ones are listed below.

Absorption coefficient, symbol K. The absorption coefficient K is defined by an equation of the form

$$I = I_0 \exp(-Kx)$$

where x is the thickness of the specimen, and I_0 and I are the initial and transmitted intensities (or powers) respectively. Then we have

$$\begin{aligned} K &= 4\pi k/\lambda_0 \\ &= \sigma/\epsilon_0 c_0 n' = 2\pi\sigma/\omega\epsilon_0\lambda n' \qquad (7) \end{aligned}$$

Reflexion coefficient (at normal incidence), symbol R

$$R = [(n' - 1)^2 + k^2]/[(n' + 1)^2 + k^2] \qquad (8)$$

Phase shift on reflexion (at normal incidence), symbol ϕ

$$\tan\phi = -2k/(n'^2 + k^2 - 1) \qquad (9)$$

Velocity of propagation through medium, symbol C

$$C = c_0/n' = c_0\lambda/\lambda_0 \qquad (10)$$

where λ is the wavelength in the medium and λ_0, c_0, the wavelength and velocity in free space respectively.

The Faraday effect. The plane of polarization of a p polarized wave is rotated by an angle θ when passing thro a conducting medium in the presence of a magnetic parallel to the direction of propagation. Though the e of a magnetic field on the dielectric constant (and hence has not yet been discussed, it is clear from Section 2 tha is a function of the magnetic field. Hence for the sak completeness we can include in this section the relation

$$\theta = (t/2)(\omega/c_0)(n'_+ - n'_-)$$

where t is the thickness of the specimen and n'_+ and n'_- the values of n' for the right-hand and left-hand circul polarized components of the plane polarized wave Section 6).

5. APPROXIMATIONS

It is clear from inspection of equations (8), (6), (5), and (2) that the reflectivity, for example, cannot be dedu exactly, even in the absence of a magnetic field and at nor incidence, without a formidable amount of computat We shall now obtain a number of approximate soluti appropriate to certain ranges of frequency and conductiv

Low conductivity material. The lattice contribution the dielectric constant n^2, cannot be less than unity an in fact, about sixteen for germanium. The free ca contribution to the dielectric constant will be small if

$$\sigma_0 \ll \omega\epsilon'$$

Hence, if condition (12) applies, we have

$$\epsilon'/\epsilon_0 \simeq n^2 \simeq n'^2$$

for all values of $\omega\tau$ (equations 2 and 5).

The absorption coefficient now reduces to

$$K = (\sigma_0/\epsilon_0 c_0 n)[1/(1 + \omega^2\tau^2)]$$

which is clearly independent of frequency at low frequen and starts to fall with increasing rapidity when $\omega\tau$ is a unity. The equivalent circuit is now an *RC* network, inductance component having been eliminated by condi (12).

For $\omega\tau \ll 1$, equation (14) reduces to

$$K = \sigma_0/\epsilon_0 c_0 n \equiv 1635\sigma_0/n \text{ in (dB/m)}$$

For $\omega\tau \gg 1$, equation (14) reduces to

$$K = \frac{1}{\epsilon_0 c_0 n} \cdot \frac{\sigma^2 q^2}{\omega^2 m^2 \mu^2} = \lambda_0^2 \left(\frac{\mu_0}{\epsilon_0}\right)^{\frac{1}{2}} \left(\frac{Nq^3}{4\pi^2 n m^2 c_0^2 \mu}\right)$$

where use has been made of equation (4). This is the in red free carrier (or "λ^2") absorption referred to in m publications on semiconductors.

Finally, to put the above equations into perspective, should put in some practical figures for *N*-type germaniu

(i) the equality $\sigma_0 = \omega\epsilon'$ occurs at 3×10^{10} c/s (λ = 1 for 2 Ω cm material;
(ii) the condition $\omega\tau = 1$ occurs at about 3×10^{12} (λ = 100 μ) at room temperature.

At low temperatures the carrier mobility, and hence increases so that $\omega\tau = 1$ at lower frequencies. For exam $\omega\tau = 1$ at about 3×10^9 c/s (λ = 10 cm) at liquid hel temperature.

Higher conductivity material. If the conductivity increased so that condition (12) is reversed, equation can still apply at high frequencies provided σ_0 is not too la Hence the absorption coefficient still decreases with cy at sufficiently high frequencies. We shall now show, ver, that there is a range of frequencies over which K ases with ω and hence K passes through a maximum. e equivalent circuit analogue the inductive free carrier has become significant and maximum absorption occurs sonance.

e shall reverse condition (12) so that

$$\epsilon'\omega \ll \sigma_0 \qquad (17)$$

hence, from equation (5) putting $\epsilon'/\epsilon_0 \ll \sigma/\omega\epsilon_0$ we have

$$n'^2 \simeq \sigma/2\omega\epsilon_0 \qquad (18)$$

putting $\omega\tau < 1$ the absorption constant becomes

$$K = \frac{\sigma_0}{\epsilon_0 c_0 n'} \simeq \frac{1}{c_0}\sqrt{\frac{2\omega\sigma_0}{\epsilon_0}} \qquad (19)$$

h increases with frequency. Equation (19) is the classical ula for the absorption of a metal (though its reciprocal, d the skin depth, is more commonly quoted).

learly, therefore, K passes through a maximum. The rmination of the exact position of the maximum requires erical computation. In addition, the maximum is very unless $\omega\tau$ is greater than unity at the resonant frequency. is condition is met, the resonance frequency, called the ma resonance frequency, is given by

$$\omega_p = (\sigma_0/n^2\epsilon_0\tau)^{\frac{1}{2}} \qquad (20)$$

$$\omega_p = (Nq^2/n^2\epsilon_0 m)^{\frac{1}{2}} \qquad (21)$$

eferring again to the tuned circuit analogue of a block emiconductor, we see that a sharp resonance can only ır if the inductive component is large and the resistive ponent relatively small. Reference to equations (2) (3) shows immediately that the larger the value of τ the e favourable this ratio is. In fact, the quantity $\omega\tau$ is analogue of $Q = \omega CR$ in the tuned circuit.

THE EFFECT OF A MAGNETIC FIELD

the presence of magnetic field applied in the direction propagation of the wave, the dielectric constant and ductivity are

$$\frac{\epsilon'}{\epsilon_0} = n^2 - \left[\frac{\sigma_0}{\omega\epsilon_0} \cdot \frac{\omega\tau \pm \mu B}{1 + (\omega\tau \pm \mu B)^2}\right] \qquad (22)$$

$$\frac{\sigma}{\omega\epsilon_0} = \frac{\sigma_0}{\omega\epsilon_0} \cdot \frac{1}{1 + (\omega\tau \pm \mu B)^2} \qquad (23)$$

re equations (22) and (23) reduce to equations (2) and (3) ero magnetic field. In the derivation of equations (22) (23), the plane polarized wave is considered as the sum a left-hand and a right-hand circularly polarized wave, positive and negative signs of μB giving the propagation stants of each component wave respectively. To deduce Faraday rotation, for example, n'_+ is obtained by taking positive sign for μB in equations (22) and (23) and n'_- by ing the negative sign. The mobility μ is interpreted as *Hall* mobility when it appears with the magnetic field. Hall and drift mobilities are significantly different in a iconductor like germanium, particularly at low tem- ature.

nspection of equations (22) and (23) shows immediately v the presence of a magnetic field can affect the optical l microwave properties of a semiconductor. Of particular ortance is the condition

$$\omega\tau = \mu B \qquad (24)$$

which leads to a maximum in the conductivity and, for not too large values of σ, a maximum in the absorption constant. This condition is referred to as cyclotron resonance.

Clearly, from inspection of equation (32), the maximum in σ at cyclotron resonance will not be sharp unless

$$\omega\tau > 1$$

On the other hand, very large values of $\omega\tau$ will necessitate very large magnetic fields at resonance unless μ is large. In practice, the wavelength range from 0·05 mm (50 μ) to a few millimetres is relatively inaccessible experimentally, so experiments on cyclotron resonance are carried out at low temperatures and microwave frequencies or at room temperatures and infra-red frequencies.

The cyclotron resonance experiment represents a relatively simple and direct method of obtaining the effective mass of the carriers, as condition (24) may be re-written, using equation (4)

$$m = qB/\omega$$

The position of maximum absorption will not, of course, correspond *exactly* with the cyclotron resonance condition but can be deduced from it numerically if required.

THE FAILURES OF THE DRUDE–ZENER THEORY

In the subsequent sections we will be concerned with the application of the Drude–Zener theory to the experimental results obtained on semiconductors. At the outset, however, it may as well be admitted that the theory fails to describe real semiconductors on two main counts, as follows:

(*a*) *The assumption of classical statistics.* In effect it is assumed that the energy absorbed by the carriers from the radiation is a small perturbation compared with the mean carrier energy. This assumption may be written as

$$h\omega \ll 2\pi kT \qquad (25)$$

where h is Planck's constant and k is Boltzmann's constant. We may therefore define a critical temperature at a given wavelength, or a critical wavelength at a given temperature, below which quantum effects will be important. For example, some anomalies observed in cyclotron resonance studies of germanium at very low temperatures have been interpreted as quantum effects.(2) At room temperature, condition (25) indicates a critical wavelength of 40 μ: this is unfortunate, as it implies that equation (16) is not valid at ordinary temperatures throughout the most accessible part of the infra-red spectrum. This problem has been studied theoretically by Spitzer, Collins and Fan,(3) who show that the right-hand side of equation (16) should be multiplied by

$$(h\omega/2\pi kT)^{\frac{1}{2}} \text{ when } h\omega \gg 2\pi kT \qquad (26)$$

which leads to a $\lambda^{3/2}$ variation with wavelength rather than a λ^2 relation.

(*b*) *The assumption of a single, isotropic value of τ* (*or m*). For a simple gas of charged particles (e.g. in the ionosphere) this is a very reasonable assumption, but it is not *necessarily* valid in any semiconductor, and is, in fact, found to be invalid for both electrons and holes in silicon and germanium. To avoid digging deep into quantum mechanics, which would be out of place in the present article, we may simply state the results.

(i) The effective mass of the holes is not single-valued though it is very nearly isotropic with respect to the crystal lattice.

(ii) The effective mass of the electrons is anisotropic with respect to the crystal lattice but is otherwise single-valued.

For most purposes, for example d.c. conductivity, the occurrence of a multiplicity of mass values is irrelevant; the effective mass of the carrier in d.c. conduction processes is an average value. In cyclotron resonance, on the other hand, the carrier mass appears explicitly and, in effect, the r.f. conductivity is given by a sum of terms like that in equation (23), suitably weighted for the relative concentrations of each type of carrier.

THE SUCCESSES OF THE DRUDE–ZENER THEORY

The experimental study of the interaction of electrons and holes in solids with electromagnetic waves is limited by the relative inaccessibility of the very long wavelength infra-red region, extending roughly from 50 μ to a few millimetres wavelength. Outside this region the theory has had ample experimental confirmation, which we will illustrate by a few examples.

Microwave frequencies. Equation (15) has been confirmed quantitatively over a range of temperatures at 8 mm wavelength.(4) The effective carrier mass does not appear explicitly in this equation so no knowledge of its value is required. Benedict and Shockley,(5) and more recently Goldey and Brown(6) have used equation (2) (or its more complicated equivalent taking the anisotropy of m into account, see Herring)(7) to deduce the effective carrier mass from the variation of dielectric constant with temperature and impurity concentration. Rau and Caspari(8) have measured the Faraday rotation in germanium at 3 cm wavelength. Working at room temperature, both μB and $\omega\tau$ (equation 22) were appreciably less than unity so no cyclotron resonance condition was achieved. The Hall mobilities of electrons and holes, deduced from this experiment, were in adequate agreement with the generally accepted values.

Infra-red frequencies. Free carrier absorption, increasing approximately as the square or three-halves power of the wavelength (equations 16 and 26) has been observed in many semiconductors, for example germanium, silicon, indium antimonide, the lead sulphide group, silicon carbide and tellurium. *N*-type germanium has been studied in most detail and, in particular, a three-halves power law confirmed.(3) The absolute magnitude of the absorption coefficient indicates that the effective electron mass is about one-tenth the free mass of an electron. This is an average value, in the sense described in the previous section, and is in adequate agreement with the value deduced from cyclotron resonance data.

The simplified equations (16) and (26) are based on the assumption that the free carriers make a negligible contribution to the dielectric constant at infra-red frequencies. That this assumption may not be valid, at least very near to a semiconductor surface, is implied by the infra-red reflectivity results obtained by Filinski.(9) Because of the presence of surface states, the carrier concentration near a germanium surface may greatly exceed the volume density, and, in addition, the value of τ may be reduced by the proximity of the surface. Further study of these effects would probably be of value in the understanding of semiconductor surfaces. For example, the variation in reflectivity with gaseous ambient conditions might yield useful information.

Resonance phenomena. Of all the free carrier phenomena studied in semiconductors, cyclotron resonance has received the most attention. The foregoing theory has indicated need to make $\omega\tau$ much greater than unity, which dict the experimental conditions used; namely, microwave quencies and low temperatures to increase τ. If infra frequencies are used, $\omega\tau$ can be made large but the magn field required at resonance becomes very large indeed. S infra-red cyclotron resonance measurements have been m namely on indium antimonide.(10) This material has largest mobility μ of any semiconductor known, so magnetic field B is not inconveniently large.

Turning to the more conventional microwave and temperature approach, at about 4° K there are very few carriers available in germanium or silicon so the speci is normally illuminated with white light to create hole elect pairs. Hence the hole and electron densities are appr mately equal. Resonance absorptions are observed as external magnetic field is varied and, on a naïve picture, resonances might be expected, one for electrons and one holes. In fact, as the effective masses are not single-va or isotropic, additional resonances, which vary with orientation of the crystal with respect to the magnetic f are observed (see, for example, Ref. 11). From such da very detailed picture of the energy surfaces of german and silicon has been built up, but again this subject is out the scope of the present article.

Plasma resonance effects have been studied in *N*-t indium antimonide at low temperatures by Dresselhaus, and Kittel,(12) using a magnetic field to vary the pla resonance frequency. Plasma resonance effects, character by a variation in resonance frequency with carrier den can be a source of confusion in cyclotron resonance stu but can be minimized by keeping the carrier density s and choosing suitable geometrical configurations.(12)

ELECTRICAL MODULATION OF THE OPTICAL PROPERTIES OF SEMICONDUCTORS

In almost all semiconductors additional free carriers be produced by illumination within the fundamental abs tion band of the material. Modulation of the carrier den by mechanically interrupted light is normally used, example, in cyclotron resonance studies, resulting in a v large improvement in the sensitivity of the technique. some semiconductors, notably germanium and silicon, has been known for many years that the carrier density increased by injection when a current is passed throug forward biased rectifying contact. The increase in den that can be achieved is limited, in general, by the finite l time of the injected carriers, but this property allows infra-red and microwave properties listed in the previ sections to be modulated electrically, which gives a r degree of freedom in optical studies.

More recently it has been found that, in germanium silicon at least, the carrier mobility can be varied by application of a sufficiently high electric field. It has b anticipated for some time that Ohm's law could not be va for any conductor at sufficiently high electric fields but, fields of the order of 1 kV per cm would be required, the po dissipation in metals would be prohibitively high. In g manium, however, such fields may be reached with destruction of the sample and it has been shown by Ryder and Gunn(14) that the current becomes independent of electric field when it exceeds about 4 kV per cm. Under s conditions no power can be absorbed from an incid electromagnetic wave as no additional current flows in sample owing to the superimposed r.f. electric field.

al, it can be shown(15) that, at microwave frequencies ast ($\omega\tau < 1$), the appropriate conductivity to use in tions (2), (3), etc. is the *slope* conductivity $\partial I/\partial E$, rather I/E. These two quantities are, of course, identical at electric field, but the former approaches zero as the nt saturates at high fields.

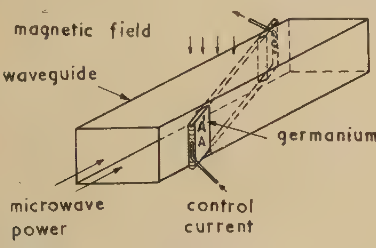
e high-field effect, therefore, provides another technique h can be applied to the study of the optical properties ee carriers in germanium and silicon. In the following ons we will describe past applications of these techniques indicate what might be done in the future.

INJECTION MODULATION

at the infra-red absorption of germanium at wavelengths ter than 1·8 μ can be increased by injection was first onstrated by Gibson(16) and almost simultaneously by man(17) and Briggs and Fletcher.(18) The application of technique to a 2 μ infra-red communication system was ribed by Gibson.(16) As the absorption per carrier is l at 2 μ, in spite of the small effective mass of electrons ermanium, it is desirable to have a considerable optical in the specimen (1 cm or greater). Owing to the high ctric constant of germanium, an infra-red beam may be ot in" by total internal reflexion. A compromise must nade between modulation depth and frequency response, a 10 kc/s response can be achieved without undue ifice.

he increased absorption per carrier at longer wavelengths es the technique considerably more attractive above ut 10 μ. Gunn and Hogarth(19) have described an ction modulator for use at microwave frequencies in ch the attenuation may be varied by 30 dB or more. le the device offers no significant advantage over a te at centimetre wavelengths, its principles may find lication in the millimetre and submillimetre regions of spectrum. The method of injection used is also sufficiently sual to justify description.

schematic diagram of this modulator is shown in Fig. 1. germanium specimen is about 0·006 in. thick and of r-intrinsic N-type material. It is placed at an acute angle he narrow face of the waveguide to minimize reflexion . One side of the plate A' is treated by abrasion and the r side A by etching, resulting in large and small values ectively for the recombination velocity s of electrons holes at the two surfaces. Ohmic connexions are made pposite sides of the plate, through which a current is ed, and a magnetic field is applied in the plane of the ad face at right angles to the current flow. The magnetic l has the effect of deflecting both holes and electrons er towards the large s surface or away from it, depending the direction of the current flow. In the first case the ier concentration is decreased, since the minority carriers the compensating majority carriers are destroyed at this ace and only generated slowly elsewhere in the specimen. In the latter case the carrier density is increased, since the free carrier pairs excited at the high s surface are removed from it and can only recombine slowly. The response time of the modulator is dictated by the transit time of carriers across the specimen and is typically a few microseconds.



ig. 1. Schematic arrangement of microwave attenuator

Turning to more fundamental applications of injection modulation it will be seen that, by measurement of the variation of modulation depth with wavelength for a given modulation current, the wavelength dependence of the free carrier absorption can be deduced without confusion from lattice, impurity or other absorption bands.

A focused beam of infra-red light may be used as a probe for the investigation of carrier concentration disturbances. Harrick(20) has shown how this technique may be applied to deduce the surface recombination velocity and carrier lifetime in germanium crystals. If the additional carriers are injected by short wavelength light no contacts need be made to the crystal for this type of measurement,(21) a technique which may be of value in crystals having a carrier lifetime affected by soldering or alloying operations.

HIGH FIELD MODULATION

That the microwave absorption of N-type germanium could be reduced to a negligible value by the application of a high electric field, as discussed in Section 9, was first demonstrated by Arthur, Gibson and Granville.(15) The external field, which was pulsed to reduce heating effects, was applied parallel to the electric field owing to the r.f. power in the guide, the general arrangement being shown in Fig. 2. The cross-section of the guide was reduced in the E direction to reduce the voltage required to achieve a given field, and injection from the positive connexion was inhibited by the use of an $N+$ type contact.

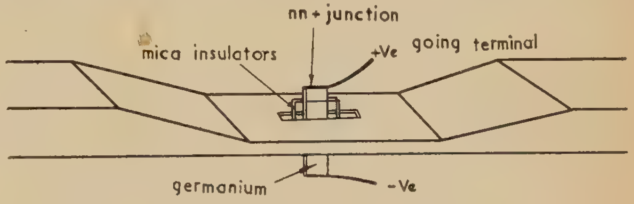


Fig. 2. Schematic diagram of the transparitor

Direct measurement confirmed that the microwave absorption was proportional to the slope conductivity $\partial I/\partial E$. Considered as a device this technique is very expensive in driving power but it has one outstanding feature—speed of modulation. The change in absorption is limited only by the rate at which electrons can absorb energy from the applied field, a time of the order of the carrier collision time τ (Section 3). Hence a response time of about 10^{-12} s is to be expected theoretically, though it must be admitted that the response has only been examined experimentally with pulse rise times of about 10^{-9} s duration!

The possible applications of the high field modulation technique are numerous. Two particularly justify especial mention, as follows.

(*a*) *The study of small deviations from Ohm's law.* If, in the above experimental arrangement a pulsed electric field is used and the microwave crystal detector is fed to an a.c. coupled amplifier, the output signal is proportional to the change in absorption coefficient, if the latter is small. That is, for small signals

$$\text{signal} = \text{constant}\,[(\partial I/\partial E)_0 - (\partial I/\partial E)_E]$$

a quantity which is very sensitive to small departures from Ohm's law. Using relatively simple apparatus, a departure of 1 part in 10^6 can be detected,(15) and it is estimated that using superheterodyne methods 1 part in 10^9 should be measurable. Electron scattering processes are still poorly understood even in germanium, (there is still no universally accepted theory of the temperature dependence of the mobility despite extensive study) and the study of small perturbations at low fields should yield valuable information. Arthur, Gibson and Granville(15) found that, at fields up to a few hundred volts per centimetre, the mobility of electrons in germanium was given by a relation of the form

$$\mu = \mu_0[1 - (E/E_0)^2]$$

but there is a substantial discrepancy between the experimental and theoretical values of the constant E_0.(22) The form of the expression arises from the conservation of energy requirements. (It has been found(23) that the same expression holds for *P*-type germanium and *N*- and *P*-type silicon up to a few hundred volts per centimetre.)

(*b*) *The measurement of drift mobility at high fields.* The deduction of carrier mobility, defined as velocity per unit field, from measurements of conductivity is not very satisfactory. For example, the dimension "time" appears through the calibration of a resistor. Haynes and Shockley(24) devised some years ago an elegant technique in which the drift of injected carriers down a rod of germanium was observed directly, the carrier velocity being measured, in effect, by a stop watch and a ruler. This technique cannot be applied at high electric fields, however, as the direct effect of the applied field on the detector contact swamps the small signal due to the injector contacts. This difficulty can be overcome by using the microwave absorption as a detector of the presence of injected carriers and in this way Gibson and Granville(25) have studied the drift mobility of carriers in germanium up to several kilovolts per centimetre. The results obtained confirm that the saturation effects observed by Ryder and Gunn (Section 9) are due to saturation of the carrier drift velocity, as anticipated by them. An additional feature of the experiment is that it should be applicable to any semiconductor, provided the carrier lifetime is at least a few tenths of a microsecond.

GENERAL CONCLUSIONS

The study of the infra-red and microwave properties of free carriers in semiconductors, particularly cyclotron resonance phenomena, has yielded valuable fundamental data on the electronic processes occurring in solids. There is no reason to believe that this field is exhausted provided that new techniques are brought to bear on the problems.

External modulation of the carrier density and mobility is just such a technique. Injection of carriers, however, is of limited value as it is difficult to control the density and distribution of the carriers. The high field effect, on the other hand, does not suffer from these limitations. At least at microwave frequencies the effective value of the conductivity can be adjusted to any desired value, including near-zero values. So far only the variation in microwave absorption with electric field has been measured and, even here, more work remains to be done [Section 11(*a*)]. The field effect might be profitably applied to the other important optical quantities, e.g. the reflectivity, phase shift in transmission* and resonance effects. The study need not be limited to room temperatures: the field required to saturate the electron drift velocity decreases with decreasing temperature, t reducing the Joule heating problem.

Finally, in case the impression has been given that fundamental problems remain, the description of an exp ment that failed should be added. It is reasonable to ded from the foregoing theory, that the application of a h electric field would affect the infra-red free carrier absorp in germanium. This effect has been looked for by Gran and Gibson(26) and not found. The magnitude of the carrier absorption at zero field was known and tests indica that the equipment was capable of detecting a change few per cent in this value, but no change was observed. reason for this failure is not known.

Note added in proof

The change, due to the application of an electric field the phase shift of 8·6 mm radiation transmitted thro germanium has recently been observed by Dr. J. W. Gran of this laboratory. I am indebted to Dr. Granville permission to give this information.

REFERENCES

(1) Seitz, F. *Modern Theory of Solids*, p. 638 *et* (New York: McGraw-Hill Book Co. Inc., 1940).

(2) Fletcher, R. C., Yager, W. A., and Merritt, F. *Phys. Rev.*, **100**, p. 747 (1955).

(3) Spitzer, W., Collins, R. J., and Fan, H. Y. *P* *Rev.*, **98**, p. 1536 (1955).

(4) Gibson, A. F. *Proc. Phys. Soc.* [*London*], *B*, **69**, p (1956).

(5) Benedict, T. S., and Shockley, W. *Phys. Rev.* p. 1565 (1953).

(6) Goldey, J. M. and Brown, S. C. *Phys. Rev.* p. 1761 (1955).

(7) Herring, C. *Bell Syst. tech. J.*, **34**, p. 237 (1955).

(8) Rau, R. R., and Caspari, M. E. *Phys. Rev.*, **100**, p. (1955).

(9) Filinski, I. *Phys. Rev.*, **107**, p. 1193 (1957).

(10) Burstien, E., Picus, G. S., and Gebbie, H. A. *P* *Rev.*, **103**, p. 825 (1956).

(11) Dresselhaus, G., Kip, A. F., and Kittel, C. *P* *Rev.*, **98**, p. 368 (1955).

(12) Dresselhaus, G., Kip, A. F., and Kittel, C. *P* *Rev.*, **100**, p. 618 (1955).

(13) Ryder, E. J. *Phys. Rev.*, **90**, p. 766 (1953).

(14) Gunn, J. B. *J. Electronics*, **2**, p. 88 (1956).

(15) Arthur, J. B., Gibson, A. F., and Granville, J. *J. Electronics*, **2**, p. 145 (1956).

(16) Gibson, A. F. *Proc. Phys. Soc.* [*London*] *B*, **66**, p. (1953); *Electronics*, **27**, p. 155 (Oct., 1954).

(17) Newman, R. *Phys. Rev.*, **91**, p. 1311 (1953).

(18) Briggs, H. B., and Fletcher, R. C. *Phys. Rev.*, p. 1342 (1953).

(19) Gunn, J. B., and Hogarth, C. A. *J. Appl. Phys.*, p. 353 (1955).

(20) Harrick, N. J. *Phys. Rev.*, **103**, p. 1173 (1956).

(21) Harrick, N. J. *J. Appl. Phys.*, **27**, p. 1439 (1956).

(22) Gunn, J. B. *Progress in Semiconductors*, Vol. 2, p *et seq.* (London: Heywood and Co., 1957).

(23) Granville, J. W. Private communication.

(24) Haynes, J. R., and Shockley, W. *Phys. Rev.*, **81**, p. (1951).

(25) Gibson, A. F., and Granville, J. W. *J. Electronics* p. 259 (1956).

(26) Granville, J. W., and Gibson, A. F. Private c munication.

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* See "Note added in proof."

Magnetic deflexion of electron beams without astigmatism

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[*Paper received* 17 *March*, 1958]

An electron beam passing through a magnetic deflecting field is, in general, subject to astigmatism. For circular pole-pieces, this takes the form of focusing in the plane of deflexion; for square pole-pieces, focusing perpendicular to the plane of deflexion. Deflexion free from astigmatism can be achieved by means of circular pole-pieces from which semicircular portions have been removed. An application of this to reflexion electron microscopy is described.

athode-ray tubes, electron microscopes and mass spectro- hs, electron beams are frequently required to be deflected ugh considerable angles in magnetic fields. In general deflexion is accompanied by aberrations,(1) astigmatic sing being particularly objectionable as it leads to a loss seful intensity.

has been shown by Grümm(2) that the aberrations can rinciple be eliminated if the deflecting fields are properly ributed. This involves making the signs of two of ser's aberration coefficients (a_8 and a_{13}) different, so that, ffect, two aberrations cancel.

is a little difficult to visualize clearly the connexion veen Glaser's coefficients and the physical structure of ecting systems; an appeal will therefore be made to nentary theory, and some structures relatively free from gmatic focusing will be described.

GNETIC FIELDS DUE TO SQUARE POLE-PIECES

onsider the motion of electrons in a magnetic field duced by two square pole-pieces (Fig. 1). If the electrons nowhere close to the corners of the pole-pieces, the exion θ is given approximately by:

$$\sin\theta = -\int_0^\infty (eH/mcv)dz \qquad (1)$$

orykin and others(3)). In this, H = field normal to e-pieces, e = electronic charge, m = electronic mass, velocity of light, v = velocity of electrons, and z is isured along the initial direction, normal to the edges of pole-pieces.

the pole-pieces have square cross-sections of side s, if the field is regarded as fairly constant between them, idly falling to zero beyond the edges, an approximate ie for θ is given by:

$$\sin\theta = -eHs/mcv \simeq 0{\cdot}3Hs/\phi^{\frac{1}{2}} \qquad (2)$$

in gauss; ϕ, the accelerating potential, in volts).

imultaneously with the deflexion, *focusing* occurs in a ie perpendicular to the plane of deflexion. This is n by:

$$y'' = -(e/mcv)(\tan^2\theta/\sin\theta)(Hy)' \qquad (3)$$

which y is measured along the direction normal to the s of the pole-pieces and dashes indicate differentiation h respect to z. The equation has been solved by numerical gration for several practical cases, and these show that greater part of the focusing takes place near the exit of the deflector. For most purposes it is sufficient to the approximate form:

$$(y'/y)_{z=s} = -(eH/mvc)(\tan^2\theta/\sin\theta) \qquad (4)$$

or, in terms of an effective focal length f_0:

$$(1/f_0) = -(eH/mvc)(\tan^2\theta/\sin\theta) \qquad (5)$$

By virtue of equation (2), this may be written:

$$(1/f_0) = \tan^2\theta/s \qquad (6)$$

Thus for a deflexion of 45° the focal length perpendicular to the plane of deflexion is equal to the breadth of the pole-pieces. In typical cases this would be of the order of a few centimetres.

It is easy to see physically how the focusing comes about. Near the edges of the pole-pieces the lines of force bend outwards, so that, except in the plane of symmetry between the pole-pieces, there is a small component of field, shown in Fig. 1, perpendicular both to the edges and to the main component of field H. On the exit side, the electrons cross the small component of field obliquely, and therefore experience a force directing them towards the plane of symmetry. There is no such focusing on the entrance side, as the electrons enter the field in a direction perpendicular to the edge, and so parallel to the small component of field.

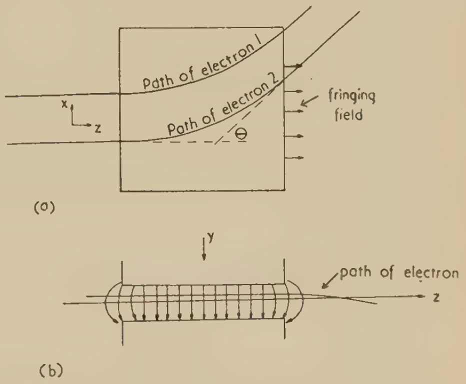

Fig. 1. Effect of square pole-pieces

No focusing takes place *in* the plane of deflexion, since electrons entering the deflector on parallel paths travel the same distance in the field, and are therefore deflected through the same angle.

Focusing solely in a direction perpendicular to the plane of deflexion is thus characteristic of pole-pieces from which electrons emerge obliquely to the "fringing" field; this will be referred to briefly as the "obliquity effect."

MAGNETIC FIELDS DUE TO CIRCULAR POLE-PIECES

Consider the motion of electrons in a field produced by two circular pole-pieces (Fig. 2). By symmetry, an electron initially directed towards the centre will emerge in a radial direction, that is, parallel to the fringing field. There will therefore be no forces tending to move the electrons closer to the plane of symmetry between the pole-pieces; hence there will be no focusing perpendicular to the plane of deflexion.

On the other hand, electrons entering on parallel paths travel different distances in the field. Fig. 2 shows that an electron entering above the diameter travels a shorter distance in the field than one entering along the diameter, and is therefore deflected less. Hence focusing occurs *in* the plane of deflexion. Simple geometry shows that this corresponds to a focal length f_{PD}(PD = "path difference") where:

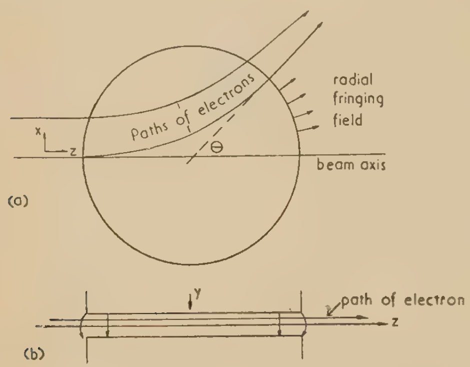

Fig. 2.—Effect of circular pole-pieces

$$(1/f_{PD}) = (eH/mvc) \tan X \qquad (7)$$

in which X is the angle between the portions of surface at which the electron enters and leaves the deflector. For pole-pieces of circular cross-section, X coincides with θ, the angle of deflexion; the general definition applies to pole-pieces of less simple form (see Fig. 5). The factor (eH/mvc) is the reciprocal of the radius R of the electron path.

If the diameter of the circular pole-piece is D, there is a simple geometrical relation between D and R:

$$(D/R) = 2 \tan (X/2) \qquad (8)$$

Hence $$(1/f_{PD}) = (2/D) \tan X \tan (X/2) \qquad (9)$$

Thus for a deflexion of 45° the effective focal length is approximately equal to the diameter of the pole-pieces. It is, therefore, numerically almost identical with the focal length f_0 corresponding to square pole-pieces of breadth $s = D$. The two focal lengths, however, represent focusing in perpendicular planes.

Focusing solely *in* the plane of deflexion is characteristic of pole-pieces which electrons enter and leave perpendicularly to the edges. It is convenient to refer to this as the "path difference" effect.

Qualitatively, f_0 and f_{PD} may be associated with Glaser's coefficients a_8 and a_{13}, but this analogy must not be pressed too far as it is not entirely precise.

NON-FOCUSING POLE-PIECES

In view of the fact that path difference and obliquity effects are of similar order for pole-pieces of similar dimensions, and that they take place in perpendicular planes, an anastigmatic deflexion system might be constructed in two stages, comprising one round and one square pair of pole-pieces. The deflected electrons could thus be successively focused in two planes at right angles, and the resultant stigmatic focu could be removed if required by conventional electron ler This depends on the cancellation of large opposing eff (compare a_8 and a_{13}). A system which to a great ex eliminates both kinds of focusing will now be described.

Fig. 3 shows the outline of a pair of round pole-pi from which a semicircular section has been removed. radius of the section is half that of the pole-pieces, and midpoint of its diameter is displaced from the centre of pole-piece by one quarter of the radius of the pole-pi Some typical trajectories are shown in Fig. 3. In plot these, it has been assumed that the circular motion of electrons starts and stops sharply at the edges of the p pieces. This is an approximation of the same order as which has already been used in deducing the formulae fo and f_{PD}. Fig. 3 shows that the path difference effect been almost entirely eliminated, owing to the different len of path cut out by the semicircular gap from the two jectories. (The distance between the paths has been ex gerated for clarity—in practice the breadth of a beam wo be much less than the radius of the pole-piece.) It is seen that the obliquity effect has been practically elimina since electrons entering along a diameter leave nearly rad Small obliquity effects arising at the edges of the se circular gap are of opposite sign and tend to cancel.

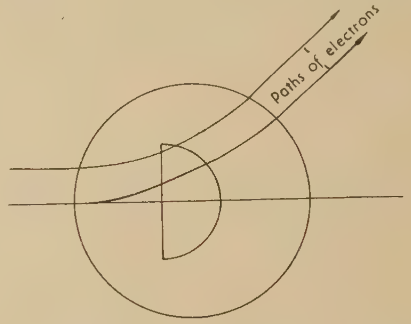

Fig. 3. Round pole-pieces with corrective gap

APPLICATION TO ELECTRON MICROSCOPY

In reflexion electron microscopy, a convenient metho illuminating the specimen without tilting the electron through large angles is to pass the electron beam through successive magnetic fields, deflecting it first outwards then inwards, and causing it to impinge on the plane of specimen at a glancing angle which may be controlled varying the current exciting the magnetic fields.(4) As matic focusing, which extends the cross-section of the be into a long ellipse and leads to a loss of intensity, constit a serious defect, since intensity is inherently low in reflex microscopy.

One possible anastigmatic system is shown in Fig. 4. first deflector comprises round pole-pieces with a se circular gap as described in the preceding section. second deflector comprises rectangular pole-pieces, and placed symmetrically between the first deflector and specimen; thus electrons enter and leave it symmetric experiencing equal and opposite obliquity effects, but path difference effects. As the inward and outward obliq effects occur successively rather than simultaneously, cross-section of the emerging beam will be slightly ellipti but insufficiently so to cause any practical difficulty. tracing indicates that it should be possible by this mean ve (glancing) angles of 40° to 50° without objectionable matism. This system resembles that given by Ito, Ito, u and Miyamae,(5) save that no mention is made in paper of a semicircular gap.

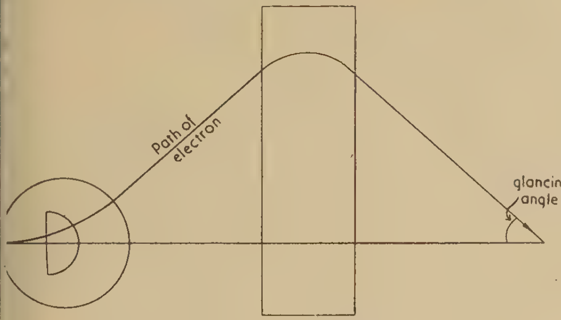

Fig. 4. Symmetrical deflexion system

ne chief disadvantage of the system described lies in the e which it occupies. In order to provide adequate ration between the second deflector and the specimen, allowing the specimen to be inserted conveniently, the ht of a typical microscope might have to be increased nore than six inches, which is undesirable for mechanical ons. If the second deflector were simply displaced in the ction of the first, the symmetry properties would be lost, uncompensated obliquity effect would result.

he situation can be ameliorated in the manner of Fig. 5. ffect, the second deflector has been displaced towards first, but it has also been bent so as to meet the in-coming trons at a more favourable angle. In the example shown, e is three times as much separation between the specimen second deflector as between the deflectors. This corre- nds to the relative spacings in the system of reference.(4) he entrance surface of the second deflector is made centric with the first deflector. The exit surface should , strictly, be fashioned according to

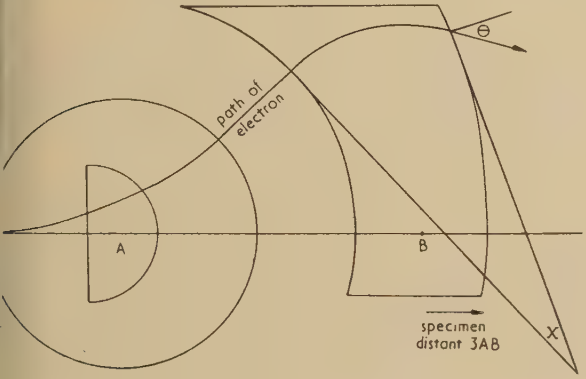

Fig. 5. "Three-to-one" deflexion system I

$$\tan^2 \theta/\sin \theta = \tan X \qquad (10)$$

ations (6) and (7)], thus making the path difference and quity effects equal, and producing stigmatic focusing. ractice, it is sufficient to make $\theta = X$, so that the exit ace has three times the radius of curvature of the entrance ace.

disadvantage of the asymmetric system is that the ward deflexion is three times the final glancing angle. At higher angles, aberrations not accounted for in the simple theory set in, and it is therefore not possible satisfactorily to achieve glancing angles greater than 15° or 20°. For most applications of reflexion microscopy, however, angles of this order are adequate.

An alternative system, which produces very little astigmatism either of the "path difference" or the "obliquity" variety, is shown in Fig. 6. The radius of the exit surface of the second deflector is still three times that of the entrance surface, but in the opposite sense. Hence electrons enter and leave parallel to the fringing field, and experience no obliquity effect. (As in the case of the first deflector, there are small obliquity effects in the V-shaped gap, but these tend to cancel.) Also electrons on parallel paths travel nearly the same distance in the field, and path difference effects are practically absent.

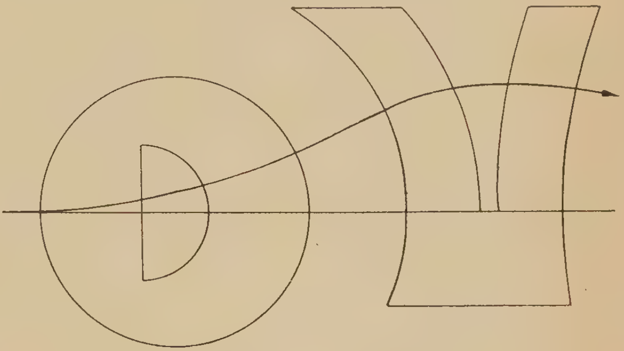

Fig. 6. "Three-to-one" deflexion system II

COMPARISON WITH EXPERIMENT

The astigmatism due to path difference and obliquity effects can be related to f_{PD} and f_0 by reference to Fig. 7. A focal length f implies a change of direction $\delta\psi = \rho/f$ in the marginal rays, where ρ is the radius of the aperture following

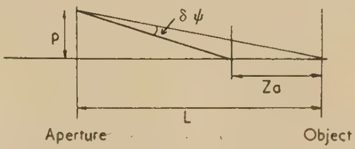

Fig. 7. Relation of focusing effects to astigmatic distance Z_a

the condenser lens. A deflector having a value of f_0 (or f_{PD}) equal to f causes the marginal rays to be refracted through an extra angle $\delta\psi$ and to come to a focus at a point distant Z_a from the object, where, from simple geometry

$$Z_a = L^2/f \qquad (11)$$

L being the distance from aperture to object. Z_a represents the distance between the astigmatic foci; it is related to the diameter δ of the disk of least confusion by

$$\delta = Z_a \alpha \qquad (12)$$

where α is the angular semi-aperture, approximately equal to ρ/L.

Two early deflexion systems are shown in Fig. 8. A rough idea of the astigmatism to be expected from system *A* can be gained by noting that a net deflexion angle of $n°$ corresponds to an outward deflexion of $3n°$ and an inward deflexion of $4n°$, and applying equation (6) to find the corresponding focal lengths of the outward and inward deflectors. These can then be combined in opposition by the ordinary optical formula and the overall focal length substituted for f in equation (11). The value of α being known (0·001 in the cases considered), equation (12) gives the disk of confusion. A similar use of equations (7) and (9) gives the disk of confusion for system B. Theoretical curves obtained in this way are compared with experiment in Fig. 9. As would be expected, system A exhibited a large obliquity effect and system B a large path difference effect.

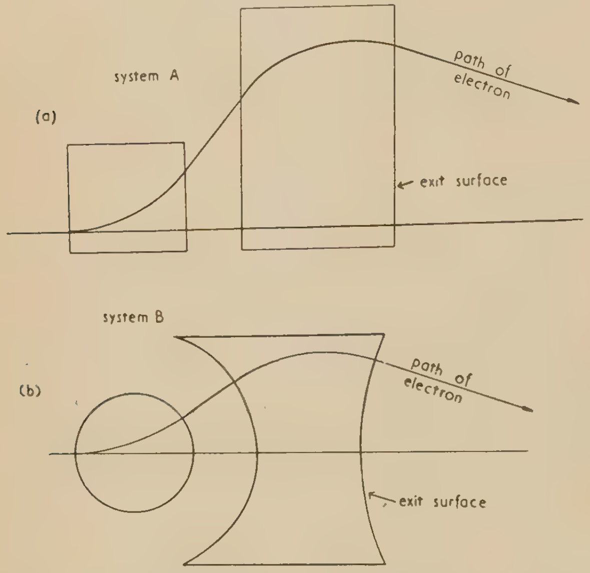

Fig. 8. "Square" and "round" deflexion systems giving respectively "obliquity" and "path difference" effects

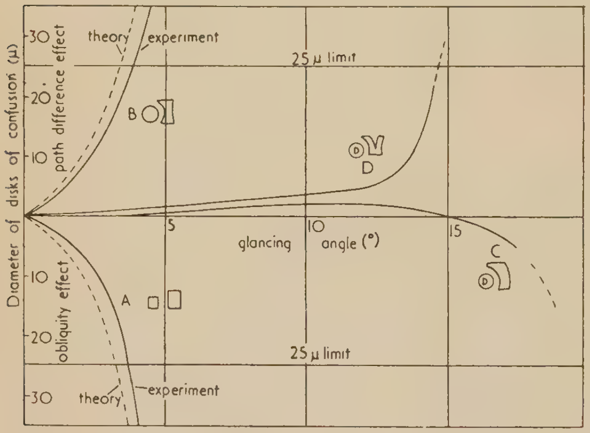

Fig. 9. Relation of disk of confusion to glancing angle for various deflexion systems

The systems of Figs. 5 and 6 yielded respectively curves C and D in Fig. 9. For the particular application in question, it was desired that Z_a should not exceed 25 mm, corresponding to a disk of confusion of diameter 25 μ. The system of Fig. 5 fulfils this up to glancing angles of 18°, and that of Fig. 6 up to 15°. (Experience shows that the latter can be improved a little by rotating the second deflector through a few degrees in its own plane.)

TOLERANCES

The accuracy with which such systems have to be m and set up may be roughly estimated as follows. In the of obliquity effect, the extra convergence brought about b displacement $\delta\theta$ in the angle between the trajectory and normal to the surface is given by

$$\delta(1/f) = [\partial(1/f)/\partial\theta]\delta\theta$$
$$= (2/s) \tan\theta \sec^2\theta\delta\theta$$

For present purposes, the side length s of the deflector be taken as 2 cm. For a reasonable angle of deflexion, 45°, this gives

$$\delta(1/f) = 2\delta\theta(\text{cm}^{-1})$$

The specified maximum value of Z_a being 25 mm, and aperture-object distance L being 14·6 cm in the case sidered, equations (11), (13) and (14) show that

$$\delta\theta < \tfrac{1}{3}°$$

This represents the accuracy with which the two deflec have to be set relative to one another. It is convenie given as an angle, since each pole-piece is held by a si screw, and is rotated on this screw into position. In prac it is found that, for best results, the two deflectors have to set slightly away from their theoretically optimum rela position.

The tolerance relating to path difference effect is o same order as that relating to obliquity effect. Position and machining tolerances (the positioning of the hol screws and the machining of the pole-pieces) are of order of 0·01 in.

TRACKING

For ease of manipulation it is desired to operate b deflecting fields by means of a single control. The theoret relation between the current in the magnetizing coils and angle of deflexion is almost linear for the first deflec (deduced geometrically from Fig. 3, since $R \propto H^{-1} \propto$ In the case of the second deflectors (Figs. 5 and 6) the curr rises less rapidly as angle increases. In order to achieve knob control, one of several possible modifications is neec The first is to use a system of shunts in the current supp this is cumbersome. The second is to combine the curr control with a cam so as to restrict the supply to the sec deflector—in the interests of mechanical simplicity this abandoned. The preferred method, which has proved effective, is to widen the gap between the pole-pieces towa the edge corresponding to higher angles (Fig. 10). One-k control with negligible focusing is thus achieved up t glancing angle exceeding 15°.

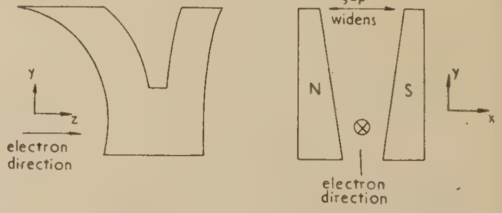

Fig. 10. Arrangement for decreasing field of secon deflector for large angles

In the microscope in question, the pole-pieces of the deflectors are also used to produce electrostatic deflexi rostatic tracking is greatly improved, without affecting magnetic properties, by filling the holes in the first ctor with copper blocks.

CONCLUSIONS

nastigmatic magnetic deflexion of electron beams can be ved by specially shaped pole-pieces, in particular ilar pole-pieces with semicircular sections removed.

an application to electron microscopy, a beam may be cted outwards and then inwards so as to strike a target rious glancing angles. Largest angles are obtained if the nd deflector, of rectangular form, lies half way between first deflector and target. However, in order to leave a space between the second deflector and target, without asing the overall length, the first deflector may be nged to deflect the beam through three times the required cing angle. Suitable shapes for the second deflector in cases are given in Figs. 5 and 6. Glancing angles in systems are necessarily less than those given by the metrical arrangement.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Glaser, W. *Elektronenoptik* (Vienna: Springer-Verlag, 1952).

(2) Grümm, H. *Optik*, **11**, p. 32 (1954).

(3) Zworykin, V. K., Morton, G. A., Ramberg, E. G., Hillier, J., and Vance, A. W. *Electron Optics and the Electron Microscope* (New York: J. Wiley and Sons Inc., 1945).

(4) Haine, M. E., Agar, A. W., and Mulvey, T. *J. Sci. Instrum.* To be published.

(5) Ito, K., Ito, T., Aotsu, T., and Miyamae, T. *J. Electronmic (Japan)*, **5**, p. 3 (1957).

Error in temperature measurement due to the interdiffusion at the hot junction of a thermocouple

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Temperature measurement errors due to interdiffusion at the hot junction of a thermocouple are discussed and corresponding theoretical expressions derived. Applying these it is found, for example, that a platinum/platinum-13% rhodium thermocouple in a gradient of 10° C/cm may be in error to the extent of about 1·3° C at all temperatures within the normal operating range following a heat treatment equivalent to 100 days at 1500° C. This is so only if the thermocouple is used in the conventional way with its arms parallel. If the same thermocouple were operated with its arms arranged in an antiparallel fashion, the error would be less.

DISCUSSION AND THEORETICAL ANALYSIS

precision thermocouple is used for a long period of time nigh temperatures, interdiffusion of the two metals or ys which form the arms of the thermocouple will occur cause a different e.m.f. to be generated, if it is subsently operated in a temperature gradient, than if no interusion had taken place. This could lead to an error in perature measurement which can be classed with other g errors since, in general, it will increase with continued of the thermocouple.

uppose that the two arms of the thermocouple are comed originally of an alloy $(1 - C_0)X + C_0Y$ and a metal X ectively, and in the first instance that they are parallel lie on the same side of the hot junction (temperature T') he tip as indicated in the figure (*a*). The small length of thermocouple symmetrically divided about the hot ction in which interdiffusion has taken place can be rded as being made up of a collection of elementary mocouples, the arms of which have a composition endent upon their distance x from the tip. Application the superposition theorem shows that the total e.m.f. erated in this region can be found by summing the e.m.f.'s to these elementary thermocouples; this is so whether or interdiffusion has taken place.

he e.m.f. ΔE developed by a typical parallel elementary thermocouple for which the temperature difference between hot and cold junctions is ΔT may be written

$$\Delta E = [(\partial E/\partial T)_{T',C(x)} - (\partial E/\partial T)_{T',C(-x)}]\Delta T \qquad (1)$$

where $C(-x)$ and $C(x)$ are the operative levels of concentration in individual arms. Here, x is always positive, the minus sign being associated with the metal and the plus sign with the alloy.

The coefficient $(\partial E/\partial T)_{T',C}$ can be conveniently approximated by a quadratic dependence on C. Thus,

$$(\partial E/\partial T)_{T',C} = a(T')C + b(T')C^2 \qquad (2)$$

and the concentration distribution following diffusion for time t can be represented by

$$C = \tfrac{1}{2}C_0\{1 + \mathrm{erf}\,[\mp x/2\sqrt{(Dt)}]\} \qquad (3)$$

where D is the diffusion coefficient, supposed independent of concentration.

It is sufficiently accurate to restrict the full calculation to diffusion which has taken place in a region extending no further than a distance of $3\sqrt{(Dt)}$ away from the hot junction; the concentration change at this distance is only about 2% of the undisturbed level C_0.

Combining equations (1), (2) and (3), the e.m.f. developed by a parallel elementary thermocouple in which diffusion has taken place is given by

$$\Delta E = C_0(a + bC_0)\,\mathrm{erf}\,[x/2\sqrt{(Dt)}](\partial T/\partial x)\Delta x$$

therefore, summing,

$$E = C_0(a + bC_0)(\partial T/\partial x)\int_0^{3\sqrt{(Dt)}} \mathrm{erf}\,[x/2\sqrt{(Dt)}]dx$$
$$= 1{\cdot}9\ C_0(a + bC_0)(\partial T/\partial x)\sqrt{(Dt)}$$

The e.m.f. that would have been generated in the same region if no diffusion had taken place is given by

$$E_0 = 3C_0(a + bC_0)(\partial T/\partial x)\sqrt{(Dt)}$$

Thus the difference between the two may be written

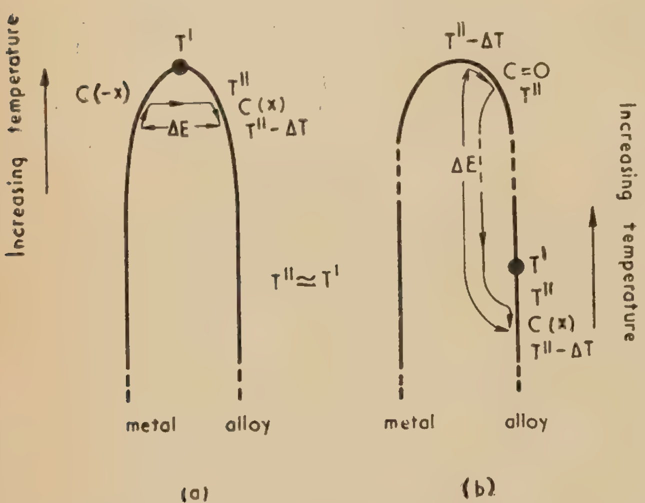
$$\delta E = E - E_0$$
$$= -1{\cdot}1C_0(a + bC_0)(\partial T/\partial x)\sqrt{(Dt)}$$

so that, dividing by equation (2), the possible error in temperature is

$$\delta T_p = -1{\cdot}1(\partial T/\partial x)\sqrt{(Dt)} \qquad (4)$$

If instead of being parallel the arms of the thermocouple were arranged to be antiparallel, as indicated in the figure (*b*), then a similar analysis yields

$$\delta T_{ap} = -0{\cdot}8bC_0[a + bC_0]^{-1}(\partial T/\partial x)\sqrt{(Dt)} \qquad (5)$$



Illustrating concept of elementary thermocouples used in calculating the effect of interdiffusion at the hot junction of a thermocouple operated with its leads either (*a*) parallel or (*b*) antiparallel

The reason for the difference between equations (4) and (5) lies in the fact that the change in the total e.m.f. of the thermocouple due to the composition change in a particular arm has the same or opposite sign(s) for each arm, depending whether or not the arrangement is parallel or anti-parallel. In the latter case, the resulting temperature measurement error is not zero owing to the non-linear dependence of the thermoelectric power on concentration.

For the most important practical case of platinum/platinum-rhodium thermocouples, $a(T')$ and $b(T')$ may be evaluated by referring to standard tables.⁽¹⁾ The value of D, unfortunately, has not been measured, but a recent investigation⁽²⁾ has yielded data for the self-diffusion of platinum. It is to be expected on the basis of Lazurus's theory⁽³⁾ of the self-diffusion of impurities in metals that the self-diffusion of rhodium in platinum will probably be less than that platinum itself. At all events the available self-diffu data for platinum may to used to find the order of magnit of the errors to be expected. The following table g some errors possible with a platinum/platinum-13% rhod thermocouple which has been subjected to a total treatment equivalent to 100 days at either 1000 or 1500 The measurements are supposed made at 1000 or 500 and in an effective temperature gradient of 10° C/ changing the sign of the gradient will change the signs of errors. It is not to be inferred from this table that error small as 0·01° C are significant with a rare metal ther couple; figures of this order of magnitude are listed beca they allow simple calculations to be made of the errors t expected following heat treatments longer than 100 days.

Temperature measurement errors (°C)

Heat treatment temperature (°C)	*Measurement temperature (°C) and arm arrangement* *Parallel* 1000	500	*Antiparallel* 1000	500
1000	−0·03	−0·03	0·01	0·01
1500	−1·3	−1·3	0·5	0·7

These errors will be increased by the contribution to mass transfer across the tip of the thermocouple caused surface diffusion. Unfortunately there is no informat available concerning the ratio between surface and volu diffusion coefficients for platinum. However, simple culations utilizing the results of experiments with silver indicate that the amount of material transferred *via* a m tomic surface layer of a 0·5 mm diameter wire will be greater than about 25% of that transferred *via* volu diffusion at 1000° C; at 1500° C the fraction is 1%. I not unreasonable to assume that the effect on the calcula errors due to this cause is of the same order.

CONCLUSIONS

It appears that errors of the type discussed will only be significance at relatively low temperatures and when tip of the thermocouple is in mechanical contact with specimen being measured. If, instead, the thermocou were immersed in a radiation bath with a temperature gradi operating, conduction losses down the leads would proba produce a much greater difference between true and indica temperature.⁽⁶⁾

Finally, it is evidently undesirable to recalibrate an thermocouple using uniform temperature baths, without having cut the tip back a distance equal to at least $3\sqrt{(}$ For the 100-day heat treatment at 1500° C, this dista amounts to 3·5 mm.

REFERENCES

(1) Barber, C. R. *Proc. Phys. Soc.* [*London*] *B*, **63,** p. (1950).

(2) Kidson, G. V., and Ross, R. Radioisotopes in Scien Research, Paper No. 216 (London, Pergamon Press L 1958).

(3) Lazarus, D. *Impurities and Imperfections* (Clevela Ohio, American Society of Metals, 1955).

(4) Hoffman, R, E., and Turnbull, D. *J. Appl. Phys.*, p. 634 (1951).

(5) Nickerson, R. A., and Parker, E. R. *Trans Amer. S Metals*, **42,** p. 376 (1950).

(6) Pease, R. S. *J. Sci. Instrum.*, **32,** p. 476 (1955).

simple phase sensitive rectifier for use with radiation detectors

By J. C. S. Richards, B.Sc., Ph.D., Department of Natural Philosophy, University of Aberdeen

[*Paper received* 4 *March*, 1958]

The ratio of light to dark resistance of a cadmium selenide photocell is sufficiently great for the cell to be used effectively as a light controlled switch. Where radiation incident on a detector is chopped at a frequency of less than 20 c/s, two such photocells can be used in a very simple arrangement to make a coherent demodulator which has the advantages of a mechanical rectifier without the usual disadvantages.

rder to obtain a good performance from a radiation tor, particularly in the infra-red region of the spectrum, common practice to modulate the incident radiation by ns of a rotating "chopper" disk. The resultant alternat- electrical signal is passed through a tuned electronic ifier and then converted to a proportional unidirectional l which may be used to actuate some form of direct nt indicator. The conversion of an a.c. to a d.c. signal be made either by a simple linear rectifier circuit (an erent detector), or by some form of phase sensitive ier (a coherent demodulator). The advantages of using ase sensitive rectifier are well known (e.g. see Smith*); nain disadvantage of the generally used systems is their ive complexity. This is particularly the case when the ping frequency is low (<20 c/s, say), and it is not enient to use transformers.

such low frequencies the obvious technique is to use an ngement of mechanical switches driven from the chopper . However, it is by no means easy to design a suitable h which will operate satisfactorily for long periods out attention; in addition, the motor driving the chopper be much more powerful than would otherwise be ssary.

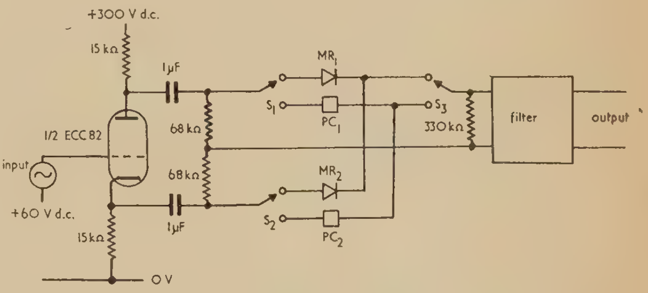
very simple device, which appears to have many of the ntages of a mechanical system without the attendant dvantages, may be made by using photoconductive cells h have a sufficiently large ratio of dark to light resistance. ch a photocell and a light source are suitably mounted pposite sides of the chopper disk, the photocell will tively act as a switch which opens and closes as the cell rkened or illuminated. Two photocells and two light ces may be used in an obvious manner to give full wave fication.

illustrate the technique a typical arrangement is ribed below. The details of the system may, of course, odified considerably to suit individual requirements.

TYPICAL ARRANGEMENT

e chopping disk is 6 in. (15·2 cm) in diameter, and has notches each 1½ in. (3·8 cm) long and of angular width cut in the circumference. Interchangeable synchronous units (Synclock by Everett Edgecumbe Ltd.) give speeds 2 and 4 rev/s, and hence chopping frequencies of 5, 10 20 c/s. Two cadmium selenide photocells (type FT422, ilger and Watts Ltd.), each having a sensitive area of n^2, are mounted at one side of the disk at opposite ends diameter and about 5½ in. (13 cm) apart. On the other of the disk an 8 V, 0·15 A torch bulb is fixed opposite cell; the light from each lamp is roughly collimated by ns of a $\frac{3}{32}$ in. (2·4 mm) diameter hole drilled in a piece etal ¼ in. (6·3 mm) thick placed between the lamp and the chopping disk. The filaments of the lamps, which are about ¾ in (1·9 cm) from their respective photocells, are heated by a 6·3 V, 50 c/s a.c. supply; there appears to be no advantage in using a d.c. supply. Obviously as the chopping disk rotates, one cell is illuminated while the other is in darkness. The dark resistance of the cells is greater than 20 MΩ; under illumination the resistance drops to about 20 kΩ.

The electronic circuit is shown in the figure. A choice of either phase-sensitive or ordinary linear rectification is given by the ganged switches S_1, S_2 and S_3, which merely replace the photoconductive cells by crystal rectifiers. In order that the phase of the input signal may be correctly adjusted, the circuit shown in the figure is preceded by one of the well-known circuits which change the phase of a sinusoidal signal without altering its amplitude. This is simpler than a mechanical adjustment at the chopper. The filter unit is of the resistance capacitance type; the number of sections and the time constant of each section may be varied.



Electronic circuit

MR_1, MR_2 = type GEX54; PC_1, PC_2 = type FT422.

If an input signal of 15 V r.m.s. is available, the output may be as large as 10 V d.c. before any non-linearity exceeds 2%. This is adequate to drive a normal pen recorder via a simple cathode follower stage. The use of the circuit at frequencies appreciably higher than 20 c/s is precluded by the finite time taken for the photocell resistance to change under illumination. If the dark resistance of a cell is taken as infinite, and the resistance under illumination as R_L, then the resistance R at time t after the cell is illuminated is given to first approximation as $R_L/[1 - \exp(-t/t_1)]$, and at time t after the cell is darkened as $R_L \exp(t/t_1)$. The exact effect of this finite response time on the performance of the present circuit is not easy to evaluate theoretically, but it is clear that the significant time constant is not t_1, but the time t_2 taken for a cell which has just been darkened to have a resistance of n times that of a cell which has just been illuminated. It may easily be shown that t_2 is equal to $t_1 \log_e(n + 1)$; if n is taken as 10, t_2 is $2{\cdot}4\,t_1$. Obviously $1/t_2$ must be (say 20 times) larger than the chopping frequency f; that is, t_1 should not be appreciably greater than $20/f$ ms.

Smith, R. A. *Proc. Instn Elect. Engrs*, **98**, p. xiv (1951).

The manufacturers of the cadmium selenide cells state that the response time varies from cell to cell within the range 1–10 ms, and that they are unable to supply selected cells having short time constants. The measured values of t_1 for the five cells available to the author were 2·5, 3, 4, 5·5 and 6 ms. This sample is, of course, too small to give an accurate indication of the distribution of response times. With the best two cells from this batch, the performance of the demodulator at 20 c/s is only just acceptable. If the input signal is adjusted to give an output of 10 V d.c. when the crystal rectifiers are in circuit, the outputs with the photocells in circuit are 9·5, 9·2 and 7·8 V d.c. at frequencies of 5, 10 and 2 respectively.

At first sight it might appear that silicon or german *p–n* junction photocells, which have a high sensitivity radiation detectors and a comparatively short response ti might be used in place of the cadmium selenide cells. fortunately, although these cells pass a large current w they are illuminated and a constant e.m.f. is applied to th their resistance is non-linear, and, provided the applied e. is greater than a fraction of a volt, they have a slope resista which is more or less independent of the illumination an the order of megohms.

A nuclear plate camera for angular distribution measurements with gaseous or solid targets over a wide range of angles

By W. M. Jones and D. G. Waters, Associated Electrical Industries Ltd., Research Laboratory, Aldermaston, Be

[*Paper received* 4 *November*, 1957]

A nuclear plate camera for the investigation of the angular distributions of charged particles from either solid or gaseous targets is described. The instrument has been checked by comparing the angular distributions of deuterons elastically scattered from gold and xenon targets, with the Rutherford scattering law down to 8° in the forward direction.

A number of angular distribution cameras have been described in the literature.(1–3) In the design of the present camera which resembles in a number of respects that described by Burrows, Powell and Rotblat,(1) the emphasis has been on the accuracy of the geometrical layout and the detection of particles emitted at small angles to the direction of the incident beam. Facilities for using either solid or gaseous targets have been provided.

DESIGN AND CONSTRUCTION

The target, beam collimator and photographic plates are rigidly mounted on a flat duralumin plate ½ in. thick and enclosed in a vacuum vessel. The layout is shown in Fig. 1 with the approximate curves of equal angle of particle emiss from the target. The dip angles of the particles entering plates are in general between 5° and 15°, and a factor of to three variation in distance from the target is obtain at certain emission angles, permitting a wide variation exposure. The track density is inversely proportional to square of this distance and the sine of the dip angle, wh taken together give an inverse cube dependence on distan

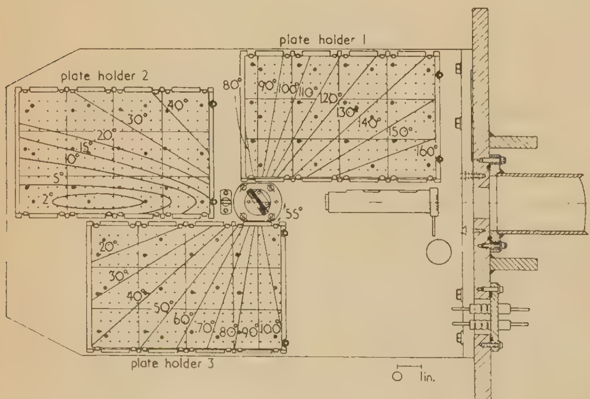


Fig. 1. Angular distribution camera

The beam collimator consists of two 0·040 in. aperture tantalum disks approximately 3½ in. apart mounted axi in the bore of a brass block which is located by dowels firmly fixed to the base plate. An anti-scatter system is ad between the collimator and target to reduce the number beam particles scattered from the collimator apertures rea ing the plates. The collimator axis intersects that of target fixing hole in the base plate which is used to loc both the solid and gaseous targets.

The gaseous target arrangement consists of the scatter gap mounted in the base plate as shown in Fig. 2. Its is fixed parallel to the beam direction. The camera vacu vessel is filled with the target gas, and the effective targe that length of beam from which particles may reach the p of observation through the scattering gap. Great care taken to ensure accurate construction and alignment of scattering gap since this is vital for accurate angular di bution measurements.

The solid target holder is designed to support the ta foil in a plane perpendicular to the base plate and incli at 55° to the beam direction. This plane contains the of the target fixing hole, whose intersection with the c mator axis defines the centre of the solid target. Thi taken as the origin of the basic reference axes of the sys ned as OX along the collimator axis OY parallel to the plate and OZ perpendicular to it.

our 5 × 2 in. nuclear plates are mounted in each of three e holders, which are accurately located around the target Fig. 1), by dowelling to the base plate. Plate holders 1 and No. 3 are parallel to the $z = 0$ plane whilst holder 2 is parallel to OY and inclined at 7° to OX, so that icles emitted at small angles to the beam direction may ecorded.

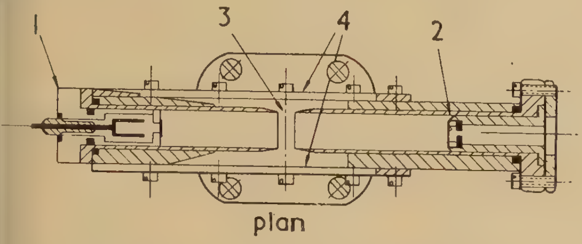


Fig. 2. Gas target arrangement

vacuum Faraday cup; 2, anti-scatter diaphragm; 3, scattering gap; 4, foil holders.

he position occupied by each portion of plate during osure must be known. This information is provided by a of dots printed on the plates while still held in the lers, by exposure to light through a mask containing a are array of 0·002 in. apertures 1 cm apart. The holes e drilled in silver solder disks 0·125 in. diameter, 0·003 in. k using a small precision drilling machine. The disks e then mounted in an array of recesses counter bored in a brass plate. The reference system is shown in Fig. 1 ether with a system of 0·010 in. diameter dots used for ntifying the plate portions, after each has been cut into e for microscope examination. The accuracy of the hanical layout is such that the co-ordinates of each tion of plate during exposure relative to OX, OY, OZ each known to about ±0·010 in.

PLATE MAPS

he relation between the curves of equal angle and the rence system must be known in a suitable form for setting plate on a microscope stage, so that portions of curves equal angle may be scanned by varying one co-ordinate the stage. The data required for this purpose were ained by measurement from plate maps and then marked tracings of the maps which were then photographed for ıre reference. The plate maps were drawn four times the ual size on "Drafting Cards (dimensionally stable)" nufactured by Kodak Ltd., the curves of equal angle being tted in correct relation to the reference dot system from a obtained by analytical geometry. The accuracy attained comparable with that of the mechanical layout.

he data shown on the map tracings for setting the plate the microscope stage are the perpendicular distances of acent reference points from the curves of equal angle, the tances of the feet of these perpendiculars from O and, in tain cases, the distances between the feet of the perpendiculars.

When the data are to be used for gaseous targets, a number minor modifications are required because of the displacent of the effective target centre from O and its variation h the point of observation. One effect of this displacement is to cause the angle of emission from the target to vary slowly along the curves of equal angle drawn for the solid target case. When the length of plate scanned is less than 1 cm the angular variation from the mean is less than ±$\frac{1}{4}$°.

ACCURACY OF LAYOUT AND MAPS

The accuracy of the mechanical layout and maps taken together is such that the distance of each point of the emulsion surface from O is known with a probable error of about ±0·020 in. This corresponds to an intrinsic error of 2% in the differential cross-section calculated from observations made at 3 in. from the target which is the smallest distance used in general. The corresponding probable intrinsic error in angle of emission is about ±$\frac{1}{3}$°.

In the present series of exposures in which 0·040 in. defining apertures were used in the collimator, additional uncertainties arose due to a possible deviation of the beam axis from OX amounting to ±$\frac{1}{2}$° in the worst case. The angular spread of particles arriving at a point of the emulsion surface from a solid target is ±$\frac{1}{2}$° at 3 in. from the target, whilst for a gaseous target it is 1·6°.

EXPERIMENTAL TESTS

The differential cross-section for the elastic scattering of deuterons in the energy range 2 to 3 MeV was investigated for both solid and gaseous targets. Gold and xenon targets were used since for these heavy elements the Rutherford scattering law seems likely to be obeyed reasonably accurately and consequently a comparison of the results with this law would serve as a check on the instrument and method of interpretation of data.

A gold foil approximately 4×10^{-6} in. thick was bombarded by a 2 MeV deuteron beam. Two exposures were carried out so that a reasonable track density could be obtained over a wide range of angles.

Two exposures were carried out with xenon gas targets each at a pressure of approximately 1·3 mm of mercury using a 2·1 MeV deuteron beam. The gas was separated from the accelerator vacuum system by a thin beam transmitting window of $\frac{1}{4}$ in. diameter, in which the energy lost by the beam was estimated as 20 keV. The windows used for each exposure were prepared by vacuum evaporation of a 0·13 mg/cm^2 aluminium layer on to a Formvar film of thickness about 0·025 mg/cm^2, followed by evaporation of a silicon monoxide layer about 0·01 mg/cm^2 thick. An aluminium absorbing foil 0·10 mg/cm^2 thick was placed on each side of the scattering gap to prevent plate fogging.

An exposure was also carried out with 2·4 MeV deuterons and a neon gas target at a pressure of 8 mm of mercury using the same system as for the xenon tests. This provides a suitable test for the energy resolution of the instrument and also for the effect of beam scattering from the various metals stops in the collimator and gas target system.

The deuteron beam was accelerated by a Van de Graaff generator$^{(4)}$ and its energy before entering the camera was measured by an electrostatic analyser.$^{(5)}$ Type C2 nuclear emulsions (by Ilford Ltd.) were used for all the exposures.

RESULTS

The results obtained for the elastic scattering of 2 MeV deuterons from gold are shown in Fig. 3 expressed as the ratio of the relative differential cross-section to cosec$^4(\theta_{CM}/2)$, where θ_{CM} is the angle of emission and σ_{CM} the differential cross-section, both measured in the centre of mass system of co-ordinates. These show that there is no marked deviation from the Rutherford scattering law in the angular range 8° to 150°, the results from the two exposures being fitted to the same straight line. The errors shown are due to the r.m.s. statistical error σ in the number of tracks. Of the nineteen observations shown in Fig. 3, three deviate from the assumed straight line by more than 2 σ.

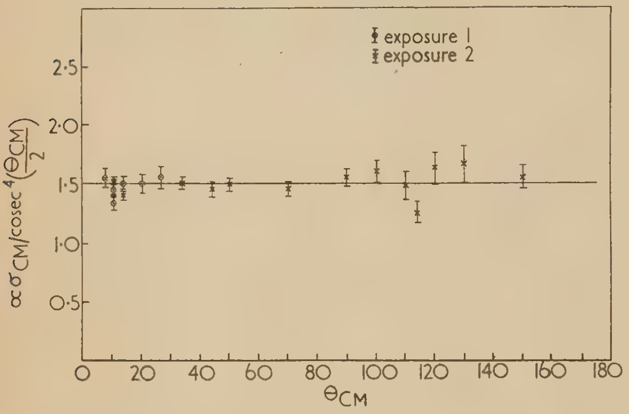


Fig. 3. Elastic scattering of 2 MeV deuterons from gold

The results obtained for the elastic scattering of 2·1 MeV deuterons from xenon are shown in Fig. 4, expressed in the same way as for gold. Again there is no marked deviation from the Rutherford scattering law in the angular range 7° to 150°. Of the observations in Fig. 4, two deviate from the assumed straight line by more than 2 σ.

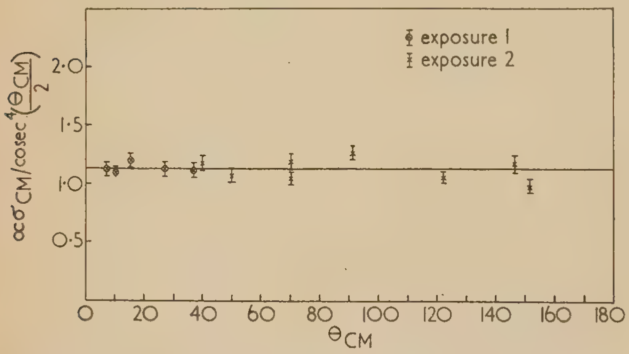


Fig. 4. Elastic scattering of 2·1 MeV deuterons from xenon

A histogram of the results obtained from the neon exposure at 20° to the beam direction is shown in Fig. 5. The p_0, p_1 and p_3 groups from the ^{20}Ne$(d, p)^{21}$Ne reaction are shown together with the d_0 group due to the elastically scattered deuterons. The relative intensities of these groups are obtained by multiplying the track numbers shown in Fig. 5 for the p_3 and d_0 groups by 3·0 and $1{\cdot}9 \times 10^3$ respectively since smaller plate areas were scanned for these. The energy of the p_0 and p_1 groups is 6·89 and 6·57 MeV respectively and the energy resolution calculated from the widths of these peaks at half maximum is 40. From Fig. 5 it may also be seen that the number of degraded beam particles reaching the plate from the various metal stops in the system is unduly high.

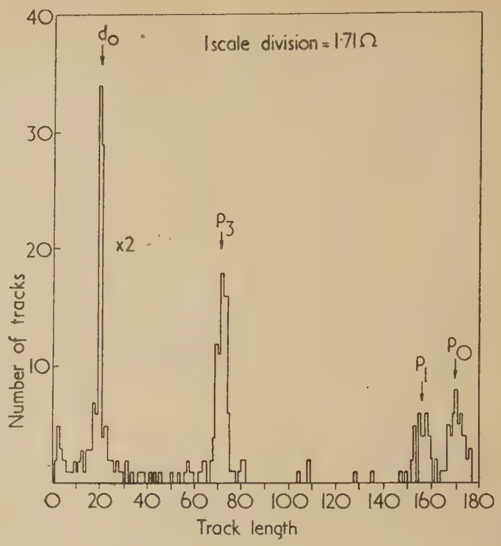


Fig. 5. Histogram of tracks from 2·4 MeV deuteron bombardment of neon (angle of observation 20° lab.)

CONCLUSIONS

The agreement obtained between the results for deute elastically scattered from gold and xenon, and the Ruther Law, is unlikely to be fortuitous and consequently the abs of serious systematic errors from the instrument and met of interpreting the data may be inferred.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Burrows, H. B., Powell, C. F., and Rotblat, J. *Pr Roy. Soc. A*, **209**, p. 461 (1951).

(2) Sanders, J. H. *J. Sci. Instrum.*, **27**, p. 100 (1950).

(3) Allred, J. C., Rosen, L., Tallmadge, F. K., Williams, J. H. *Rev. Sci. Instrum.*, **22**, p. (1951).

(4) Chick, D. R., and Petrie, D. P. R. *Proc. Instn El Engrs*, **103 B**, p. 132 (1956).

(5) Hunt, S. E., Petrie, D. P. R., Firth, K., and Tr A. J. *Proc. Instn Elect. Engrs*, **103 B**, p. 146 (1956

A mass spectrometer mass marker

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An instrument has been constructed which utilizes the galvano-magnetic effect in bismuth to measure the field strength of a mass spectrometer magnet, and hence to determine the masses of peaks as they occur when the spectrum is scanned by variation of the magnetic field strength at constant accelerating voltage. The bismuth coil is mounted between the pole-pieces of the magnet and the instrument marks on the mass spectrum a series of fifty mass calibration points at predetermined values of bismuth resistance and hence of magnetic field. Masses can be determined with the instrument to $\pm 0 \cdot 05$ mass unit in the range up to mass 200 and to an accuracy of $\pm 0 \cdot 025\%$ above this range.

INTRODUCTION

masses of positive ions collected in a sector-type mass ctrometer are given by the equation, $m = \frac{H^2}{V} \cdot \frac{R^2 e}{2}$ where s the magnetic field strength, V the accelerating voltage, he radius of curvature and e the electronic charge. Ions different mass may be recorded, therefore, by varying H V. Whichever method of scan is chosen, it is important t the mass number of any peak be known. It is not ntial, however, to know both H and V, since if, for mple, V is varied at constant H, unknown peaks may be npared in mass with known peaks, using the relationship = constant. If this method of scanning the mass ctrum is employed, there is little difficulty in measuring values of V corresponding to all peaks in the spectrum. wever, the sensitivity of the instrument is reduced at low ues of accelerating voltage, and since these correspond to h mass numbers from which the most valuable analytical ormation is often obtained, this method of scanning the ctrum is somewhat unsatisfactory. Variation of the gnetic field is free from this disadvantage, but presents a greater problem in the measurement of its value. It is y to measure the magnet current and this may be roughly ibrated in mass units at a standard accelerating voltage l this facility is normally provided in commercial instru- nts. The hysteresis of the magnet, however, reduces the uracy of such an arrangement so that it cannot provide tain identification of mass numbers in the 100 to 200 nge with the result that isolated peaks or groups of peaks this region require separate measurements for the deter- nation of their masses. A more accurate method of asuring mass during the spectrum scan is, therefore, very irable but the greater accuracy can only be obtained by asuring the field itself. Packard(1) has described a nuclear gnetic resonance probe which would enable measurements mass to be made at any position in the mass spectrum ile Caldecourt(2) has described a magnetometer which can used to record mass, but although Newton(3) has described use of a bismuth coil to measure a magnetic field, no tomatic equipment using bismuth has previously been scribed.

The galvanomagnetic effect in bismuth, that is, the change its electrical conductivity when placed in a magnetic field, very large. The valence electrons which might be available conduction are contained in states within a single llouin zone and are just sufficient to fill it. There is a y small overlap with the next zone which occurs for a very ited range of directions relative to the crystal axes. Conction is due to the relatively few electrons (about 1 in 10^3) ich are in the "outer" Brillouin zone and to the "positive holes" left behind in the "inner zone." The mean free paths of these conduction electrons in the crystal lattice is long so that bismuth is relatively a good conductor. The changes in conductivity to be expected, due to the modification of the electron paths by a magnetic field has been worked out(4) and shows that the fractional change to be expected is high and will increase rapidly as the temperature is reduced. The magneto-resistive coefficient can be greatly influenced by small amounts of impurity and it is thus desirable to use bismuth of high purity.

Using this effect, the measurement of magnetic field is reduced to the determination of the resistance of a bismuth element, provided that the instrument may be calibrated directly. Since we are not primarily interested in the absolute values of the magnetic field, but only in the values of the bismuth wire resistance corresponding to the various mass numbers, the mass spectrometer itself may be used (with a sample whose mass spectrum is known) to calibrate the equipment. We have used a complex mixture of organic compounds which gives a peak at every mass number in the range 200–50. The resistance of the bismuth wire can then be found for the magnetic field corresponding to each mass number (at a fixed accelerating voltage) and the mass of any unknown peak at the same accelerating voltage can then be determined later, simply by measuring the resistance of the bismuth. Due to the rather large temperature coefficient of bismuth, thermostating of the bismuth wire is essential.

Bismuth wire is not available commercially in this country but is advertised for sale in the United States.* The difficulties of making a suitable bismuth resistor are mainly due to the brittleness of the metal and its low tensile strength. Several methods of making wire including extrusion and casting were tried. Wire of best pliability was, however, obtained by the method described below. Molten bismuth was introduced into a glass tube sealed at one end. The sealed end of the tube was heated in a gas flame until it could be drawn out by hand, and the drawing out process continued until several lengths of bismuth wire in glass were obtained. Due to the expansion of bismuth on solidification, many of the glass tubes fractured on cooling, but it was possible to select several lengths of bismuth wire about 50 cm long and about 0·1 mm diameter. These lengths were placed in a shallow trough, and the glass dissolved away in hydrofluoric acid. A polythene former 3 mm diameter and 30 mm long was wound non-inductively with fine copper wire and a current passed through the wire to embed it in the polythene. The wire was allowed to cool, then removed from the former, leaving a groove in which the bismuth wire could be wound. Thicker copper leads (32 s.w.g.) were tied at one end of the

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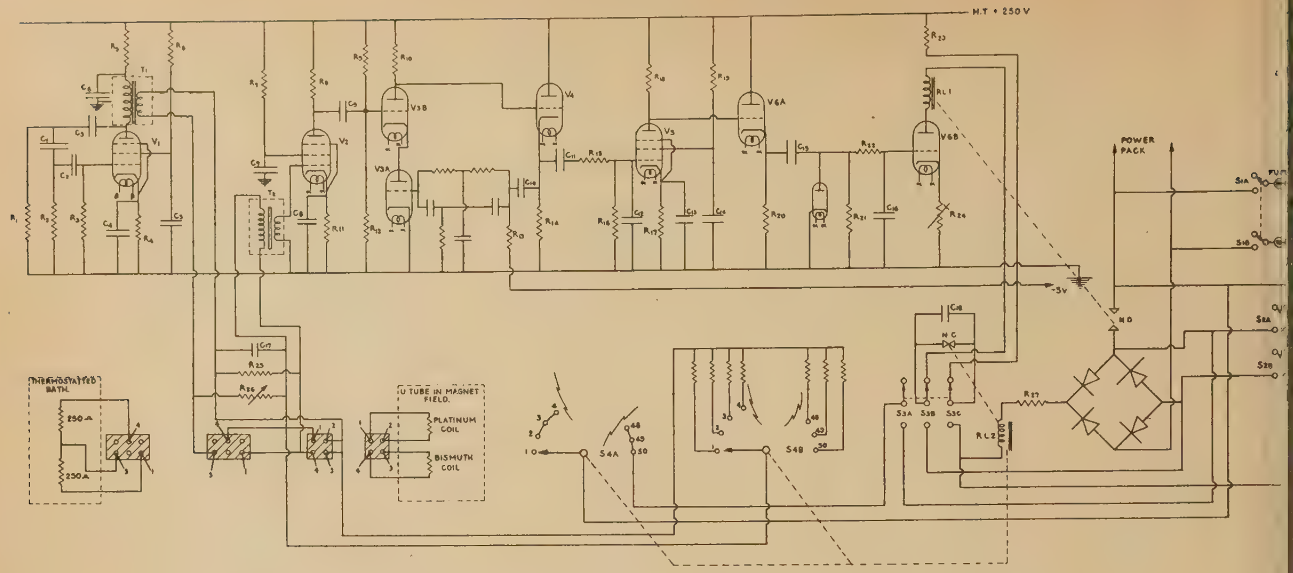
* The Fitzgerald Electrical Supply Co., Muskegan, Michigan.



Circuit of mass spectrometer mass marker

R_1 = 100 kΩ
R_2 = 470 kΩ
R_3 = 2·7 MΩ
R_4 = 1 kΩ
R_5 = 22 kΩ
R_6 = 390 kΩ
R_7 = 1 MΩ
R_8 = 220 kΩ
R_9 = 2 MΩ
R_{10} = 100 kΩ
R_{11} = 2·2 kΩ
R_{12} = 820 kΩ
R_{13} = 1 MΩ
R_{14} = 270 kΩ

R_{15} = 560 kΩ
R_{16} = 100 kΩ
R_{17} = 2·2 kΩ
R_{18} = 220 kΩ
R_{19} = 1 MΩ
R_{20} = 27 kΩ w.w.
R_{21} = 100 kΩ
R_{22} = 680 kΩ
R_{23} = 22 kΩ
R_{24} = 1 kΩ
R_{25} = 330 Ω
R_{26} = 20 kΩ
R_{27} = 100 Ω (100 W)

C_1 = 300 μμF
C_2 = 10 μμF
C_3 = 0·001 μF
C_4 = 100 μF, 50 V
C_5 = 0·1 μF
C_6 = 1 μF
C_7 = 0·1 μF
C_8 = 100 μF, 25 V
C_9 = 0·01 μF
C_{10} = 0·1 μF
C_{11} = 0·01 μF
C_{12} = 0·0005 μF
C_{13} = 50 μF, 12 V
C_{14} = 0·1 μF

C_{15} = 0·1 μF
C_{16} = 0·1 μF
C_{17} = 0·013 μF

V_1 = 6SJ7
V_2 = EF86
V_3 = ECC82
V_4 = ECC83
V_5 = EF86
V_6 = ECC82

T_1, T_2 transformers type D-160-D (by Muirhead and Co. Ltd.)

Power pack type A.S. 515 outpu
200 mA, 250 V (by Solartron Elec-
tronic Group Ltd.)

Uniselector coil—type 1/DCO/281,
T24518 A, 75 Ω

Rectifiers—2 of type D. 48-13-1 FW
RL_1, P.O. type 10 kΩ
RL_2, Uniselector type

S_1, D.P.D.T.
S_2, D.P.D.T. (spring loaded)
S_3, T.P.D.T. (spring loaded)
S_4, D.P. 50-way Uniselector

former and the ends of the wire flattened. The bismuth wire was then wound non-inductively on the former, the ends of the wire being pinched under the flattened copper leads. The connexions were further strengthened by silver plating the region of each joint from potassium argentocyanide solution. The coil was then sealed in a tight-fitting polythene sleeve to protect the bismuth from accidental damage and mounted inside a glass U-tube, rigidly held between the pole faces of the mass spectrometer magnet. It was at first hoped to use a bismuth wire cooled with liquid nitrogen for measurement of the magnetic field, since at this low temperature the fractional change of resistance is many times greater than at room temperature. However, bismuth wire prepared in the above fashion broke due to thermal shock when immersed in liquid nitrogen and since it was found that an adequate sensitivity was obtained at room temperature, attempts to obtain a stronger wire were not continued. From several coils made in the above way, one of 33 Ω was chosen.

Resistance measurement of the bismuth is fully automatic, and accomplished with the system shown in the figure. The bismuth wire constitutes one arm of an a.c. resistance bridge. A second arm of the bridge contains a ten-turn helical potentiometer by means of which the bridge balance can be adjusted, and an arm adjacent to the bismuth includes a 50-way Uniselector relay operated rotary switch (by Standard Telephones and Cables Ltd.), which connects successively across this arm one of a series of 50 resistors. A condenser C_{17} of value 0·013 μF was connected as shown, it being found to improve the bridge balance. The bridge is fed from a 500 c/s single valve oscillator *via* a step-down transformer and the output of the bridge is fed *via* a step-up transformer to a selective amplifier. The selectivity of the amplifier is necessary to remove unwanted harmonics. The amplifier consists of an untuned pentode stage follo by a "cascode" stage tuned to the oscillator frequen followed by a second pentode amplifier. The output is through a cathode follower to a rectifier and the negat output of this stage is connected to the grid of a tri containing a Post Office relay in its anode circuit.

To operate the instrument, the mass spectrometer is set to the standard accelerating voltage used, the magnet curr adjusted to record a standard mass (we always use 204 mercury isotope as standard), and the bridge broug into balance by means of the helical potentiometer with Uniselector on its first position. At balance the output fr the rectifying stage is small and the current through V_{6B} large enough to operate the relay in its anode circuit, wh actuates the Uniselector and throws the bridge out of balan by a predetermined amount. At the same time, a second of contacts (not shown in the figure) on the Post Office re actuate a relay-operated pen which marks this position the record. The magnetic field is now scanned through t mass spectrum. As the magnetic field appropriate to m 201 is reached, the bridge comes into balance again, and t Uniselector and pen are again operated in the same mann A total of 50 marks corresponding to pre-selected mas can thus be marked on the mass spectrum. A switch S_3 provided which, when depressed, returns the Uniselector its starting position. A second switch S_2 moves the U selector round by one step each time it is depressed. In ord to compensate for resistance variations due to temperat changes, an arm of the bridge adjacent to the bismu resistance consists of a platinum wire having the sa resistance as the bismuth, the two being mounted togeth in the glass U-tube in the magnet gap. Since the temperatu coefficients of resistance for bismuth and platinum a ilar, the sensitivity to temperature changes of the com- ation is small. Temperature changes are reduced by npping water through the U-tube from a thermostated h, the temperature of which is controlled at 30° C by a cury-toluene regulator. Variations in the temperature of two resistors are then of the order ±0·01° C.

he criteria by which the performance of the instrument y be judged are firstly the sensitivity to changes of magnetic d or equivalent changes on the mass scale, and secondly reproducibility or freedom from drift. The practical limit he sensitivity which can be achieved is set by the amplifier se and the gain of the amplifier could, if required, be many es greater than at present. We have used a total voltage n, including the input transformer, of about 10^5, and gives an output of 10 V per mass number at mass 200. The reproducibility depends primarily on the temperature stability of the bridge resistors. All the principal resistors are in the thermostated water bath and this limits short term (i.e. the duration of a spectrum scan) fluctuations to the equivalent of 1 part in 2000 in mass. The longer term (day to day) reproducibility is not quite so good, and the instrument is therefore standardized on mass 204 as described previously prior to recording each spectrum.

REFERENCES

(1) Packard, M. E. *Rev. Sci. Instrum.*, **19**, p. 435 (1948).

(2) Caldecourt, V. J., and Adler, S. E. *Rev. Sci. Instrum.*, **25**, p. 953 (1954).

(3) Newton, A. S., and Di Grazia, H. X. U.S. Atomic Energy Commission U.C.R.L.-2994.

An apparatus for the viscometry of organic liquids at high temperature

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An apparatus suitable for the measurement of the viscosity of organic liquids at temperatures of up to 400° C is described. A sealed glass capillary viscometer is used so that oxygen can be excluded and measurements made above the normal boiling-point. The viscometer is immersed in a molten salt mixture contained in a welded tank and is viewed through special windows. These consist of Kodial polished glass disks sealed to Kovar cylinders. A rotation arrangement enables the viscometer to be inverted. Examples are given of its uses on known materials and on the effect of irradiation of para-terphenyl.

ie of the most important practical consequences of the oosure to ionizing radiations of organic liquids is the ultant increase in viscosity. The measurement of this ect is now a recognized method of assessing radiation mage. Since the variation of viscosity with temperature fore and after irradiation is required, a great number of easurements have been made at two temperatures, 100° F d 210° F, which are standard in the petroleum industry.(1) ie use of only two arbitrarily chosen temperatures has tricted the usefulness of many of the experiments. In me cases the substances were originally solid at one or th of the reference temperatures, and in others the effect irradiation was to raise the liquifying temperature of the aterials to the extent that viscosity measurements at the erence temperature were meaningless.

It has become clear(2) that it is necessary to measure the cosity of liquids before and after irradiation over a wider ige of temperatures than hitherto, and to extend the range measurements to the likely temperatures of operation in case of organic materials being considered as reactor oderator-coolants. This paper deals with a simple, robust d well-tried apparatus for measuring the viscosity of small nples of liquids at high temperatures. It is suitable for ganic materials under these conditions in that the viscoter is sealed, preventing oxidation and allowing measurents above the normal boiling-point.

The viscometer, made of borosilicate glass, is of the spended level type and resembles one used by Mesrobian d Tobolsky(3) at lower temperatures. Flow times were easured using a stop-watch graduated in 0·2 s. It was ind that at 25° C the flow times were proportional to iematic viscosity with pure water(4) and sucrose solutions(5) to within 0·2%. The height of the driving head of the liquid does not vary with its density, and the correction for temperature due to the expansion of the glass can be shown to be negligible up to 400° C if accuracies of the order of 1% are required, as here. Viscosities were calculated as proportional to flow times at all temperatures, using calibration with pure water at 25° C in an accurately thermostated water bath. Flow times were kept above 200 s and the repeatability at all temperatures was below 0·5% when steady temperature conditions had been attained.

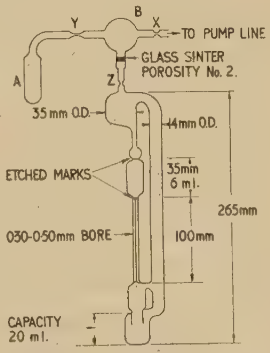

Fig. 1. Viscometer

One defect of a single sealed viscometer is the inability to vary the rate of shear. Separate experiments were carried out in an open-ended viscometer near the melting-point to avoid vaporization, in an apparatus in which different measured pressures of nitrogen could be applied to force the liquid through the viscometer.(4) It was found that for the liquids of chief interest, pure para-terphenyl, Santowax R and the irradiated materials, the viscosity was independent of the rate of shear over the range measured, i.e. (mean) shear rates in the viscometer of $5{\cdot}42 \times 10^2\ \mathrm{s}^{-1}$ to $6{\cdot}80 \times 10^3\ \mathrm{s}^{-1}$.

The filling arrangement is shown in Fig. 1. The material was sealed in the bulb *A* and thoroughly outgassed by a series of cycles of successive melting, freezing and pumping. Constriction *X* was then sealed and the material in bulb *A* was warmed and poured completely into bulb *B*, in which previously had condensed any of the test specimen which had volatilized during the outgassing operations. Constriction *Y* was then sealed and the bulb *B* warmed until the material was forced through the glass sinter by its own vapour pressure, then after sealing off at *Z* the viscometer was ready for use. Between determinations the viscometer was thoroughly cleaned with hot concentrated chromic/sulphuric acid solution.

VISCOMETER TANK

The tank (Fig. 2) is of welded $\frac{1}{16}$ in. mild steel sheet, except for the window side, which is $\frac{1}{4}$ in. thick mild steel machined for welding to $\frac{1}{16}$ in. thickness for a width of $\frac{1}{2}$ in. all round the edges. The internal dimensions are 14 × 14 × 3 in. enabling the viscometer to be rotated about a central horizontal axis, and accommodating the stirrer, controlling thermocouple, thermometer and heaters. The viewing windows are a special feature and each consists of polished Kodial glass disk, 1 in. diam. × $\frac{1}{16}$ in, sealed to the end of a short Kovar metal tube, 1 in diam. × $\frac{1}{2}$ in. The other ends of these tubes are slightly flanged and are hard soldered to a thin stainless steel panel, 3 × 9 × 0·01 in. This is sealed to the side of the tank using a copper/asbestos gasket, with a series of 4 B.A. stainless steel studs screwed into the thicker side of the tank, and stainless steel nuts and clamping frame. The heaters are Metrovick industrial immersion heaters, and are sheathed in Monel metal. The bath liquid is a mixture of salts (53% potassium nitrate, 7% sodium nitrate, 40% sodium nitrite) which melts at 120° C and can be used up to 450° C. It is useful to have the heaters arranged in a circuit such that if one fails the other takes over, since the bath material, if allowed to solidify, will crack any glass present, including the windows. The bath material has remained a clear liquid over a period of about 2 years of continuous operation. The temperature control system in use is a Kent Multelec recorder controller, which under these conditions controls to better than ±0·5° at 200° C, and to ±1·5° at 400° C. The temperature is measured by a c brated mercury thermometer. The tank has a brass lid wh carries one of the heaters and a device for holding rotating the viscometer, made of brass, shown in Fig. The construction of the device and levelling of the t

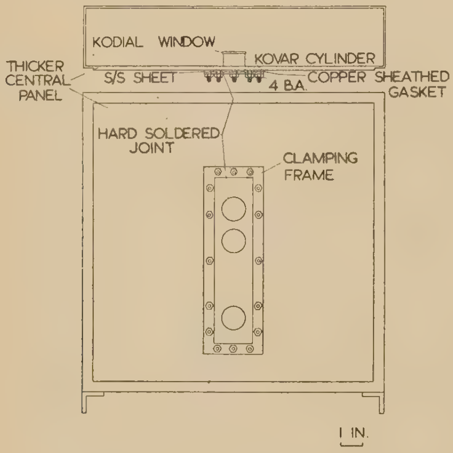

Fig. 2. Viscometer tank

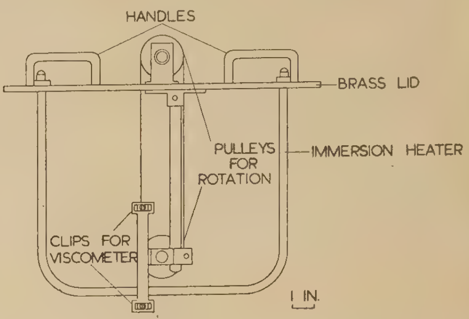

Fig. 3. Viscometer holder and rotation system

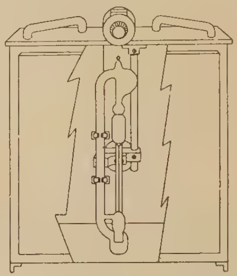

Fig. 4. Mounted viscometer

ensures that the plane of rotation is vertical. The viscome is checked against a plumb line for verticality after invers and is kept vertical by the friction against rotation. F shows a view of the mounted viscometer. The whole ta is contained in a Sindanyo housing, packed with asbes wool.

DENSITY

Density measurements are required in the same temperat range as the viscosity determinations to convert kinematic dynamic viscosities. Dilatometers were made by seal pieces of 4 mm bore Veridia tubing, 6 in. long, to bulbs 3–4 ml. capacity. The bores were determined accurately measuring the difference between two mercury levels with travelling microscope and weighing the mercury remov The dilatometers were thermostated throughout. T volumes were determined by filling to a datum mark w mercury and weighing; a meniscus correction was appli assuming both materials to have a hemispherical menis in a 4 mm bore tube. The filling arrangement was simi to that used for the viscometer, except for the absence of filtering sinter.

For heating, a bath of MS 550 silicone fluid was used, an unsilvered vacuum flask, 3 in. diam., equipped with a gl sheathed heater, and a stirrer. The dilatometer was wired a calibrated thermometer and also to a thermocouple wh actuated an "Electroflo" controller. The bath liquid w usable up to 400° C, although it fumes and tends to discolo if held at this temperature for long periods.

The difference in height between the datum mark and t meniscus was read with a travelling microscope, the menisc being illuminated from behind. The apparent volume each temperature was calculated and the true volu obtained by allowing for the expansion of the glass. T mass of material used was checked by weighing the dila r full, and again empty. The method gave excellent ement with published values(6) when calibration materials um and silver nitrates (Analar, recrystallized) were used.

RESULTS ON KNOWN LIQUIDS

ara-terphenyl. Material from L. Light and Co. was um distilled twice, the second time through a small tionating column, in each case rejecting initial and final tions. The resulting material had a sharp melting point 12·5° C in good agreement with the results of other kers.(7, 8)

able 1 gives values obtained for the dynamic viscosity of para-terphenyl together with values calculated from the es for $E\eta$ and A in the equation $\eta = A \exp (E\eta/RT)$ n by Andrews and Ubbelohde.(8) The agreement up to C, rather above the upper limit of their measurements, tisfactory.

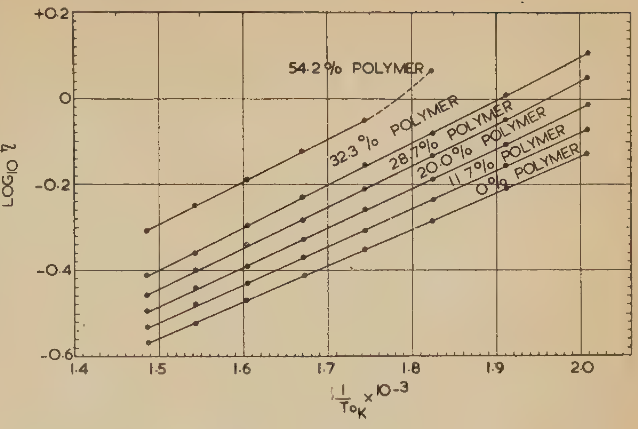

Fig. 5. Plot of $\log_{10} \eta$ against $1/T$ for Santowax R irradiated at 350° C

Table 1. *Viscosity of para-terphenyl*

perature (°C)	225	250	275	300	325	350	375	400
work kinematic viscosity (cS)	0·785	0·658	0·567	0·500	0·422	0·408	0·372	0·341
work dynamic viscosity (cP)	0·752	0·617	0·521	0·449	0·387	0·350	0·311	0·278
erence (8) (calc.) dynamic viscosity (cP)	0·736	0·614	0·521	0·447	0·390	—	—	—

Table 2. *Viscosity of sodium nitrate*

Temperature in °C	328	338	348	358
This work, large viscometer, kinematic viscosity (cS)	1·43	1·36	1·30	1·23
This work, small viscometer, kinematic viscosity (cS)	1·41	1·34	1·29	1·22
This work, large viscometer, dynamic viscosity (cP)	2·72	2·57	2·45	2·32
This work, small viscometer, dynamic viscosity (cP)	2·68	2·55	2·44	2·30
Goodwin and Mailey,(6) dynamic viscosity (cP)	2·66	2·54	2·44	2·33

e should like to recommend the use of para-terphenyl a standard in this connexion. It is comparatively to purify, it behaves as a Newtonian liquid and the of log η against $1/T$ is linear over a wide range of peratures.

odium nitrate. Hopkin and Williams A.R. material was e recrystallized from pure water and carefully dried. le 2 gives our results for two viscometers, large (7 ml.) small (2 ml.), together with those of Goodwin and iley, showing reasonable agreement.

APPLICATION TO RADIATION DAMAGE

he apparatus has been in continuous use for a period of r 2 years and an extensive series of measurements on the ct of irradiation on the viscosity of para-terphenyl and towax R has been completed. The results are reported eference (9), and an example is given in Fig. 5. This e of data is essential to a full assessment of the usefulness n organic material under reactor conditions.

ACKNOWLEDGEMENTS

e wish to thank Mr. J. D. Milne for help with the design he tank, Mr. S. W. Osborne for help and advice with the s-to-metal seals, and Mr. T. H. Bates for measurements percentage polymerization of irradiated para-terphenyl. f. A. R. Ubbelohde kindly supplied information about salt bath. We also wish to acknowledge the help and ouragement of Mr. T. F. Williams and Dr. W. Wild.

REFERENCES

(1) Collins, C. G., and Calkins, V. P. *Radiation Damage to Elastomers, Organic Liquids and Plastics*, Report APEX 261, 1956 (Cincinatti: General Electric Company, Aircraft Nuclear Propulsion Department, 1956).

(2) Colichman, E. L., and Nakazato, S. *Evaluation of Viscosity as a Measure of Pyrolytic and Radiolytic Damage in Organic Compounds*, p. 210. H. P. Smith. *Compilation of Organic Moderator and Coolant Technology*, Report TID-7007, Part I (Washington: U.S. Atomic Energy Commission, 1956).

(3) Mesrobian, R., and Tobolsky, A. *J. Amer. Chem. Soc.*, **67**, p. 785 (1945).

(4) B.S. 188: 1937, with amendments 1940, 1951, 1953; also 188: 1957.

(5) Bingham, E. C., and Jackson, R. F. *Bull. Bur. Stand.*, **14**, p. 59 (1918–19).

(6) Goodwin, H. M., and Mailey, R. D. *Phys. Rev.*, **25**, p. 469 (1907); **26**, p. 28 (1907).

(7) Sangster, R. C., and Irvine, J. W. *J. Chem. Phys.*, **24**, p. 670 (1956).

(8) Andrews, J. N., and Ubbelohde, A. R. *Proc. Roy. Soc. A.*, **228**, p. 435 (1955).

(9) Bates, T. H., Burns, W. G., Morris, B., Wilkinson, R. W., and Williams, T. F. *The Radiation and Thermal Stability of Some Potential Organic Moderator Coolants*, A.E.R.E. Report, C/R 2121, Part I (London: U.K. Atomic Energy Authority, 1957).

A critical method of focusing an optical diffractometer

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A simple but critical method of focusing the optical diffractometer is described. It depends on certain features in the intensity distribution near the focus in an error-free diffraction image of a circular aperture. Minor modifications to the optical diffractometer necessary to permit the application of the method are indicated.

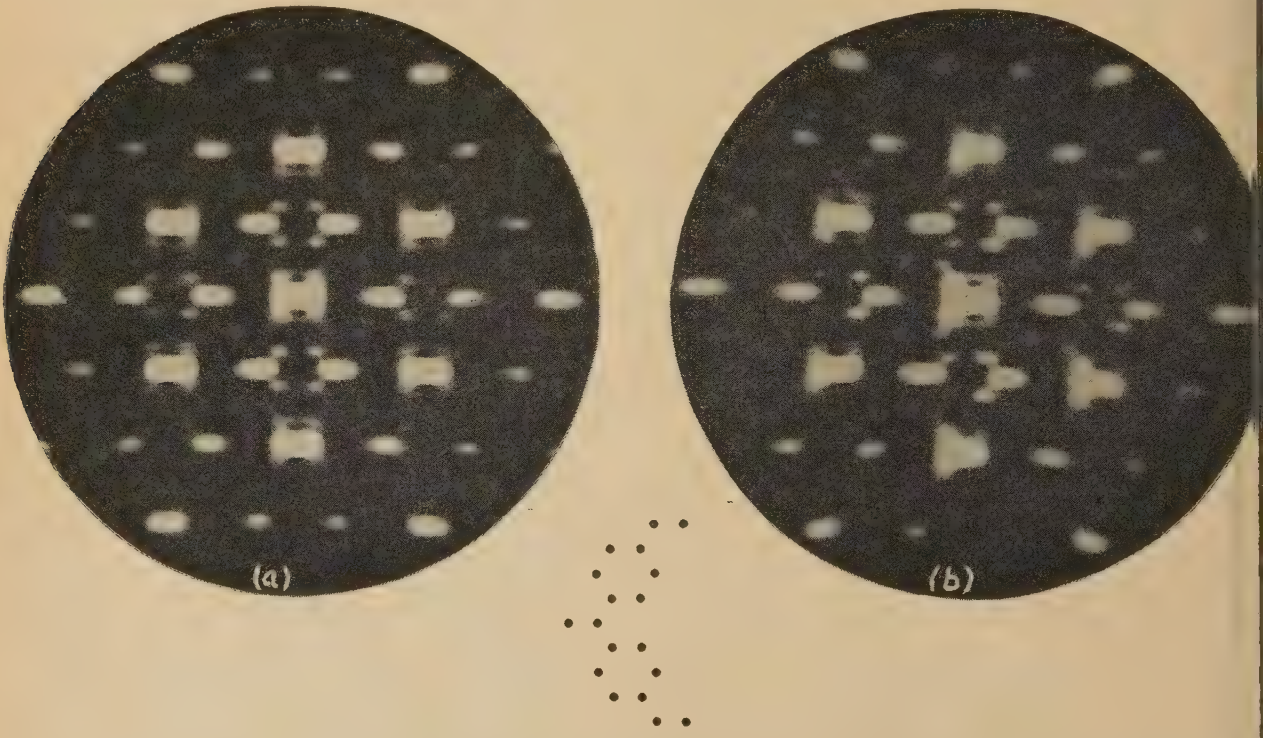
1. INTRODUCTION

In the early stages of the development of optical diffraction methods for solving X-ray diffraction problems,$^{(1, 2, 3)}$ the diffracting objects used were comparatively simple and the optical perfection of the diffractometer was not of supreme importance. Recently, however, the range of usefulness has been extended to a degree which necessitates considerable improvement in the optical design. A recent paper$^{(4)}$ describes some of the improvements which have already been made. The problem of "focusing" has, however, been a major obstacle. The difficulty is that the diffraction pattern is not a true image; it has no sharp edges or details on which the adjustment can be based. It is necessary, however, to place the film in the back focal plane of the lower lens with great precision, otherwise considerable errors are introduced—particularly with asymmetric objects. Fig. 1 shows the kind of error that is found: (*a*) is a correctly focused diffraction pattern of the mask shown at (*c*), and (*b*) is the same pattern grossly defocused (2 mm) to exaggerate the errors. The important point to be noticed is that, although there are very marked changes in the pattern, both Figs. and (*b*) appear equally "sharp" in the conventional se In (*b*) Friedel's law is not obeyed and the pattern is centrosymmetrical.

A series of experiments$^{(5, 6, 7)}$ on the purely optical asp of the diffractometer is at present being attempted and present method of focusing has arisen from these stu The theoretical background of the method is described the accent on the physical interpretation of the mathema results rather than on the mathematics. In Section 3 a adjustable camera table is described which enables the method of focusing to be carried out.

2. THEORETICAL BACKGROUND

The intensity distribution near the geometrical focus in error-free diffraction pattern of a circular aperture has calculated theoretically by Zernike and Nijboer$^{(8)}$ Wolf,$^{(9)}$ and an intensity map drawn (Fig. 2). The diag represents a section of the space on either side of the f plane by a plane containing the optical axis (*u*-axis) of



(*c*)

Fig. 1. The effect of defocusing an optical diffractometer with 11·4 cm diameter lenses of 152 cm focal length

(*a*) Diffraction pattern of mask (*c*) with film accurately in the focal plane.
(*b*) Diffraction pattern of mask (*c*) with the film displaced 0·2 cm from the focal plane.
(*c*) Mask representing a projection of one molecule of di-para-anisyl nitric oxide.

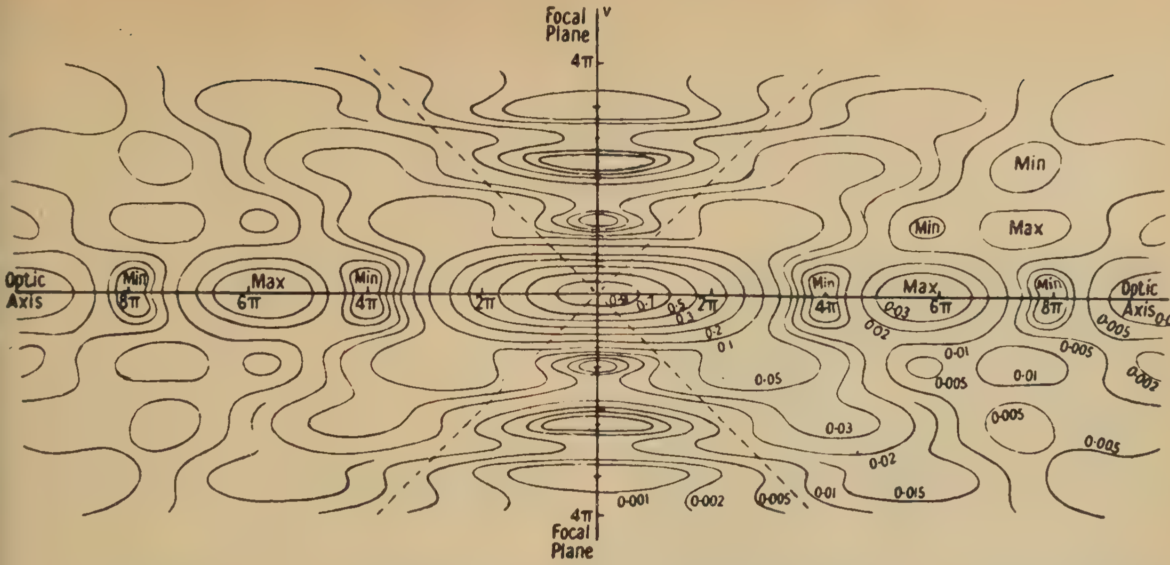


Fig. 2. Isophotes (lines of equal intensity) near the focus in a plane containing the axis of the instrument (adapted from Linfoot and Wolf(11))

ument. The origin is the geometrical focus and the is the trace of the focal plane. Since the object has ılar symmetry the diagram can be imagined as rotated ıt the *u*-axis. The pattern in the focal plane is thus seen e a central circular peak surrounded by alternate light dark rings—the familiar Airy pattern. The dark rings known as "fringes of lateral displacement"(10) and the ntity v as plotted in the diagram is such that v/π represents number of the fringes of lateral displacement counting ı the centre. If we now imagine moving the "image" e away from the focal plane, keeping both planes parallel, central large peak will expand and eventually a dark spot appear at the centre (when $u = 4\pi$). As the plane is ed further away another central maximum will develop $= 6\pi$) and thus a system of circular fringes is built up. number of complete dark fringes—"fringes of defocus-(10)—present for an image plane passing through a t u is $u/4\pi$.

will further be noted that all the minima and maxima he focal plane are long in a direction parallel to the axis, that the minima along the *u*-axis are very much shorter the maxima. For this reason, and because the eye is t sensitive as a dectector of minimum illumination, the ition of a minimum may be judged with much greater cision than that of a maximum. The method of focusing sists of locating accurately the positions of the first ima on either side of the focal plane ($u = \pm 4\pi$). The metrical focus is then mid-way between these two itions or between any other corresponding pairs of ima on either side.

. MODIFICATIONS TO THE DIFFRACTOMETER

n the diffractometer used for the present series of experiıts special arrangements have been made for photophy. Fig. 3 shows the unit which now replaces the roscope unit on the instrument as described by Hughes Taylor.(3) The "film table" or "camera table" *A* is ntially a disk about 1 in. in diameter with a hole about . in diameter at its centre which is to be placed accurately he back focal plane of the lower lens of the diffractometer. A piece of film clamped firmly to the table will then record the required image.

A plate *M* is clamped to the framework of the diffractometer and carries slides *D* in which the rest of the unit can move up and down. Coarse adjustment can be made by releasing the clamping screw *E* and moving the whole unit. When *E* is tightened the knurled wheel *G* and thread *F* provide a fine adjustment. The table *A* can also be moved up and down relative to the rest of the unit by rotation; it forms one part of a micrometer screw, the other part being firmly attached to the rest of the unit. A microscope can be attached by means of the studs *KK′* so that the appearance of the image in the plane of *A* may be examined visually.

For photography a large casette holding a complete 25 m reel of 35 mm Pan microfile film is used. A section of this is shown in Fig. 4. The film from the drum *S* passes over the spool *T* under the spring-loaded platform *R*, round a second spool *U* and finally over the driving sprocket *V*. Before winding the film on, the platform is raised by the plunger *W*. To mount the camera for use, the shaft carrying the cams *L* (Fig. 3) is rotated by the knobs *C* to raise the slides *BB′* into their upper position. The camera then slides into *BB′* until the window *P* (Fig. 4) is over the table. The safety shutter which slides over the window is opened automatically by a projection on the slides. The slides *BB′* are then lowered and the table *A* enters the camera and the film is trapped between the table *A* and the spring-loaded platform *R*; it is thus in the required plane. (The whole diffractometer is mounted in a dark room.) A vernier scale is provided so that the position of the assembly can be recorded.

A small adaptor carrying a piece of film on which some fine fringes have been photographed is used for preliminary adjustment of the microscope.

4. METHOD OF FOCUSING

The instrument should, of course, be correctly alined and adjusted(4) before this procedure is begun. The adaptor is placed in position on the film table and the microscope is clamped in position. The film table *A* is then rotated until the fringes on the film of the adaptor are sharply focused.

Care must be taken that the eye is correctly accommodated by observing absence of parallax between the image and a marker placed outside the field of the microscope, but in the plane of the object, and viewed with the unengaged eye.

The adaptor is then removed and a circular aperture placed in the normal mask position of the diffractometer. The aperture should be at least as large as the overall area occupied by the largest mask likely to be used subsequently.

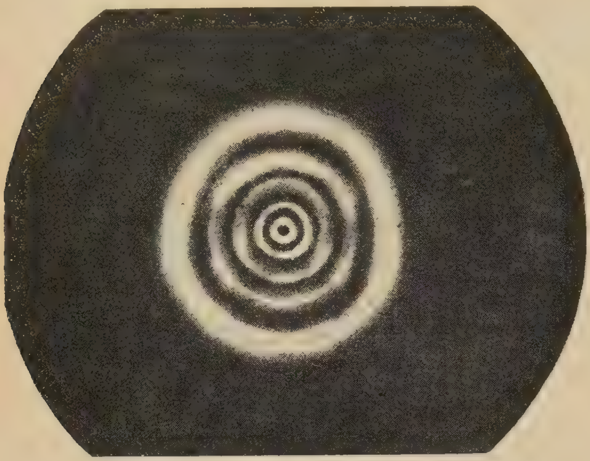


Fig. 5. Photograph of the diffraction pattern of a circular aperture at the position of five fringes of defocusing—2·64 cm from the geometrical focus—at $u = 20\,\pi$

A pin-hole source which will give coherent illumination over the area of the aperture must then be chosen.(4) The screw *E* is then unclamped and the whole assembly moved until the diffraction pattern is seen. The fine adjustment *G* is then operated to locate the various minima along the *u*-axis.

The first minimum on either side of the focal plane may be used but there is an increase in accuracy if higher order fringes are used. The fifth minimum on either side ($u = \pm 20\,\pi$) is convenient. The position of both is read

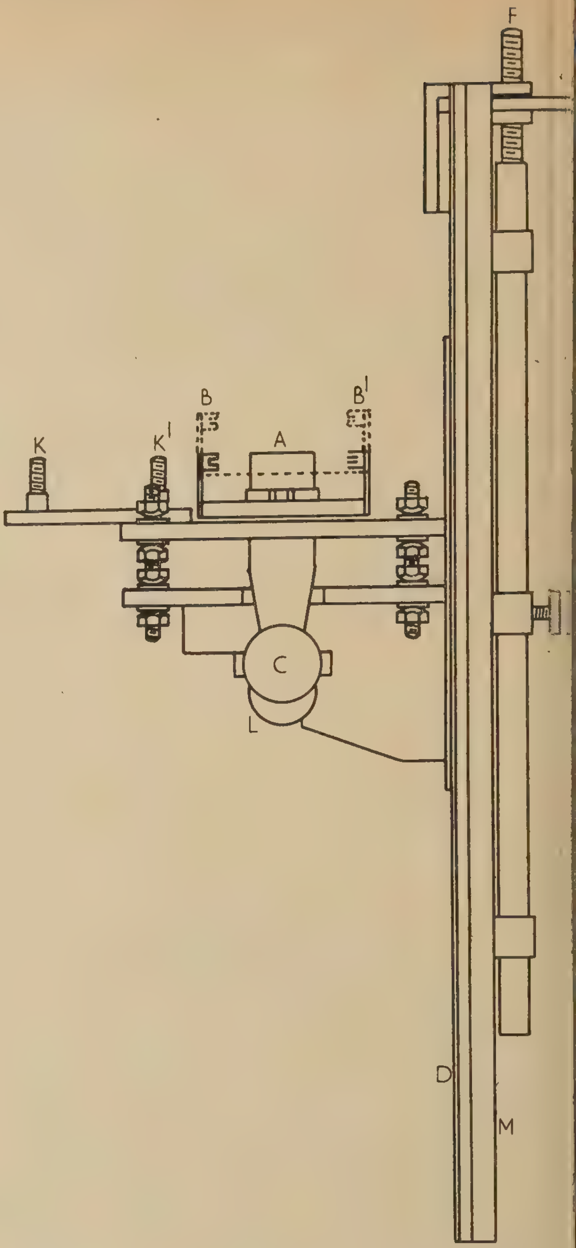


Fig. 3. The adjustable camera-table assembly

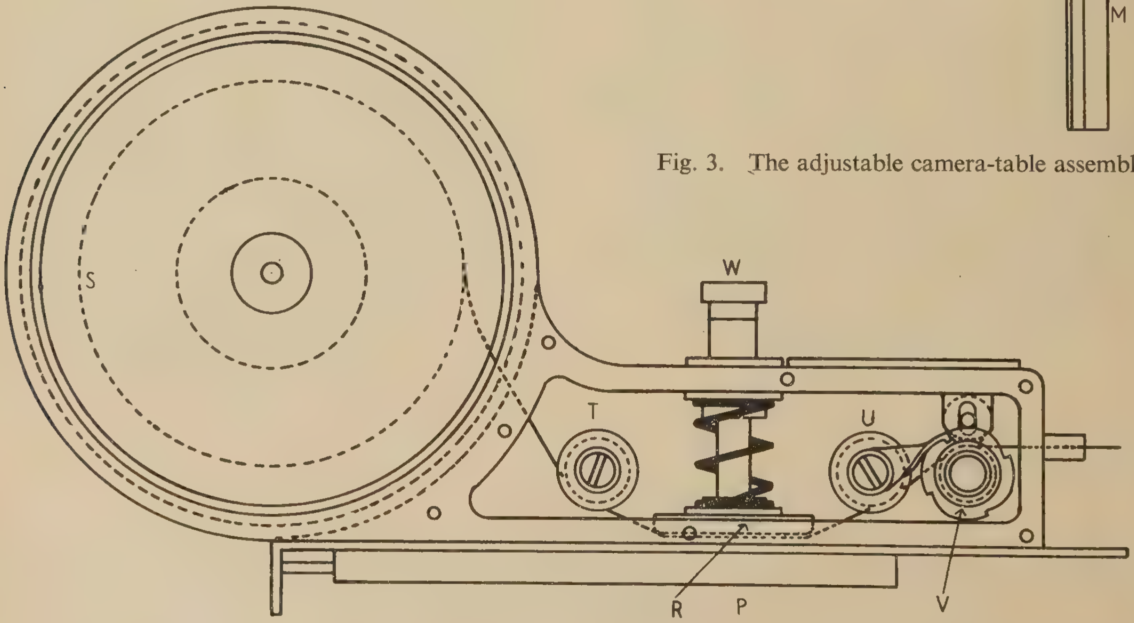


Fig. 4. The camera

ie vernier scale and the mid-point of these two is then eometrical focus. The actual pattern at $u = 20\pi$ with erture 4 cm in diameter is shown in Fig. 6.

st of the method. As mentioned in the Introduction, entrosymmetrical objects give patterns which do not Friedel's law if the focusing is not accurately done. mask used for Fig. 1 (di-p-anisyl nitric oxide(12)) has ys given trouble and, although rather better centro- ıetry than that of Fig. 1(*b*) had previously been achieved ial and error, the new method permits photographs like of Fig. 1(*a*) to be taken at the first attempt.

ACKNOWLEDGEMENTS

e wish to thank Prof. H. Lipson for his interest and uragement, and various colleagues in the Department of ics for helpful discussions.

e are also indebted to Mr. W. Hughes for constructing apparatus and for preparing the drawings for Figs. 1 4.

REFERENCES

TAYLOR, C. A., HINDE, R. M., and LIPSON, H. *Acta Cryst.*, **4**, p. 261 (1951).
(2) HANSON, A. W., LIPSON, H., and TAYLOR C. A. *Proc. Roy. Soc. A*, **218**, p. 371 (1953).
(3) HUGHES, W., and TAYLOR, C. A. *J. Sci. Instrum.*, **30**, p. 105 (1953).
(4) TAYLOR, C. A., and THOMPSON, B. J. *J. Sci. Instrum.*, **34**, p. 439 (1957).
(5) HANSON, A. W., and TAYLOR, C. A. Edited by Z. Kopal. Contribution to *Proceedings of the Symposium on Astronomical Optics and related subjects*, University of Manchester, 1955 (Amsterdam: North Holland Publishing Co., 1956).
(6) THOMPSON, B. J., and WOLF, E. *J. Opt. Soc. Amer.*, **47**, p. 895 (1957).
(7) THOMPSON, B. J. *J. Opt. Soc. Amer.*, **48**, p. 95 (1958).
(8) ZERNIKE, F., and NIJBOER, B. R. A. Contribution to *Theorie des Images Optiques*, p. 227 (Paris: Editions de la Revue d'Optique, 1949).
(9) WOLF, E. *Proc. Roy. Soc. A*, **204**, p. 533 (1951).
(10) LINFOOT, E. H., and WOLF, E. *Proc. Phys. Soc.* [*London*] *B*, **66**, p. 145 (1953).
(11) LINFOOT, E. H., and WOLF, E. *Proc. Phys. Soc.* [*London*] *B*, **69**, p. 823 (1956).
(12) HANSON, A. W. *Acta Cryst.*, **6**, p. 32 (1953).

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double γ-ray spectrometer for coincidence counting of positrons

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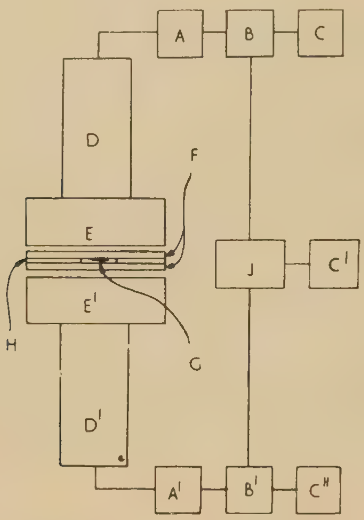
A double γ-ray spectrometer has been developed as a specific method for the counting of positrons in the presence of other β- and γ-ray emitters. It has a discrimination factor about a hundred times better than a simple γ-ray spectrometer. A method of efficiency calibration including correction for the effect of positron-γ-ray coincidences is described.

method of measuring the fast component of a neutron is by the activation of elements having suitable thresholds the (n, $2n$) process. In many cases the active isotopes luced are positron emitters, and these have to be counted ie presence of strong negative electron emission produced he competing (n, γ) process. The usual techniques of ration by absorption or decay curves in a simple β-counter often not adequate for this purpose. Therefore, to provide ecific positron counter, a double γ-spectrometer has been t for the coincidence counting of pairs of annihilation nta, and a method of calibrating the counter for absolute surements has been developed. A useful incidental antage of the system is that it does not require the paration of a thin source.

learly all positron annihilation occurs after the particle been slowed down to an energy of about 10 eV, and st of these annihilations result in the emission of two ays of energy 0·51 MeV in opposite directions. The ble spectrometer consists of an arrangement for the rgy selection and coincidence counting of these two ositely directed γ-rays. The process of energy selection ludes the case of in-flight annihilation, since the energies the γ-rays are then greater than 0·51 MeV, but this cess represents only 2% of the annihilations.(1) The tribution of three-quantum annihilation can be neglected e DeBenedetti and Siegel(2) have shown that, in solids, this process only occurs once for each 370 double-quantum processes. The mean lifetime of positrons in aluminium, which is the annihilating material in these experiments, has been shown(3) to be $1\cdot5 \times 10^{-10}$ s, so a very short coincidence resolving time can be tolerated.

EXPERIMENTAL ARRANGEMENT

The general arrangement and a block diagram of the electronic system are shown in the figure. The spectrometer consists of two cylindrically shaped NaI(Tl) crystals of diameter $2\frac{1}{2}$ in. and length 1 in. They are sealed in aluminium cans with Perspex faces and each is viewed by an E.M.I. type 6097B photomultiplier tube *via* a Perspex light guide $\frac{3}{4}$ in. long. The crystals are arranged on a common axis with their outer faces parallel and separated by a distance of about $\frac{1}{2}$ in. In this gap is located the source assembly. The source is mounted by evaporation on a sheet of 0·0005 in. Distrene supported over a central hole in a flat plate of $\frac{1}{16}$ in. aluminium. (This method is used so that the same source can also be counted for total β-activity in a standard end-window Geiger system.) The source plate slides into a close-fitting slot between two aluminium plates $\frac{1}{8}$ in. thick, rigidly supported in the gap between the two crystals so that the source is positioned on the axis of the system and about half-way between the two. Annihilation takes place in the plates and the resultant γ-rays are detected by the crystals. The output pulses from the two channels are fed *via* cathode followers and linear amplifiers (AERE type 1049B) to single-channel pulse analysers (Dynatron type N/101). The output from each analyser is fed to a scaler to record the individual channel count and to a coincidence unit (AERE type 1036) where coincidences between pulses of the selected energy range are recorded and counted on a third scaler. The differentiating and integrating time constants of the main amplifier are set at 0·32 μs, and a coincidence resolving time of 1 μs has been found suitable. The channel width of each pulse analyser is calibrated with a source of ^{22}Na and set to count only the 0·51 MeV annihilation radiation peak. The natural background of coincidence counts is about one per minute. The paralysis time of about 10 μs in each channel of the coincidence unit sets an upper limit to the counting rates which can be used.



Schematic diagram of spectrometer

A, *A′*, amplifier; *B*, *B′*, analyser; *C*, *C′*, *C″*, scaler; *D*, *D′*, photo-multiplier; *E*, *E′*, sodium iodide crystal; *F*, aluminium annihilator plates; *G*, source on Distrene; *H*, aluminium source mounting plate; *J*, coincidence unit.

EFFICIENCY CALIBRATION

The counter efficiency is determined by counting standard positron sources which are calibrated by reference to a $4\pi\beta$ counter. A correction has to be applied for sources which have γ-rays in coincidence with the positrons and an expression for this is derived as follows. Consider a positron emitter having a γ-ray in cascade in a fraction E of the disintegrations. The coincidence counting rate due to positrons alone would be $2N\omega\eta_1^2$ where N is the disintegration rate, η_1 is the efficiency of each crystal for total absorption of the 0·51 MeV γ-ray and ω is the solid angle subtended by each crystal at the source. The loss of coincidence counts caused by the simultaneous counting in either of the crystals of a Compton or photoelectric pulse from the γ-ray with energy sufficient to make the resultant pulse too high for the analyser gate is $2N\omega\eta_1^2 2\omega\eta_2 E$, where η_2 is the total efficiency of each crystal for the γ-ray. The gain of coincidences due to the recording of an annihilation 0·5 MeV γ-ray in one channel and a coincident 0·5 MeV pulse (Compton or photoelectric depending on the γ-ray energy) from the γ-ray in the other channel is $2N\omega\eta_1\omega\eta_3(1-\eta_1)E$. Here η_3 is the probab
of the latter process and the term $(1-\eta_1)$ excludes t
cases in which the other 0·5 MeV annihilation pulse is
recorded. A gain of coincidences also occurs if a Com
pulse from an annihilation γ-ray coincides in one cr
with a γ-ray pulse so as to give a total energy absorptio
0·5 MeV, while the other annihilation γ-ray is totally abso
in the other crystal. Calculation shows, however, that
contribution from this process is negligible. The contribu
from coincidences due to a Compton event in one cr
followed by absorption of the back-scattered γ-ray in
other crystal is made very small by the pulse height select
and is negligible if the γ-radiation intensity is of the s
order as that of the positron emission. The net coincide
rate is, therefore,

$$N_c = 2N\omega\eta_1^2[1 - 2\omega E\eta_2 + \omega E(\eta_3/\eta_1)(1-\eta_1)]$$

The counting efficiency for a positron and γ-ray emit
thus related to that for a simple positron emitter by
expression:

$$\text{Eff. (positron} + \gamma) =$$
$$= \text{Eff(positron)}\{1 - \omega E[2\eta_2 - (\eta_3/\eta_1)(1-\eta_1)]\}$$

Even for an extreme case with the largest practical value o
the quantity in square brackets, (i.e. the correction facto
γ-contribution) does not differ from unity by more than 0
It can be derived from the geometrical value of ω and
values of η_1, η_2 and η_3 given by the γ-ray absorption co
cients. The ratio η_3/η_1 can also be obtained experiment
from an inspection of the single-channel γ-ray spec
The quantity $\omega E[2\eta_2 - (\eta_3/\eta_1)(1-\eta_1)]$ can be estim
in this way to within about ±15% limits so the correc
factor is known within ±4% limits. Greater accuracy
be achieved by reducing ω. By the application of
expression, then, the efficiency of the counter for any posit
emitting source can be derived from the efficiency for a si
standard.

An experimental check of the above efficiency correc
calculation has been made using sources of ^{18}F, which
simple positron emitter with no γ-rays, and ^{22}Na, which
positron emitter having a 1·28 MeV γ-ray in coincide
with 99·94% of the disintegrations. The latter, havin
half-life of 2·6 years, is a convenient long-lived stand
For this experiment the counter was set with the crysta
close together as possible, so as to give the maximum v
of ω and provide a thorough test of the accuracy of
correction factor determination.

Sources were calibrated by counting a weighed portio
the source solution in a 4π β-counter. The counter
was an AERE type 1222 gas-flow proportional counter
the sources, of thickness equal to a few microgrammes
square centimetre, were mounted on gold-coated V.Y.
films of total thickness 20 to 30 μg/cm^2. (V.Y.N.S.
co-polymer of polyvinyl acetate, and polyvinyl chlo
supplied by Bakelite Ltd.) Absorption in these thin f
has been shown to be less than 1% for β-particles of t
energies.(4) The Auger electrons following K-capture
cesses do not appear to be registered in the 4π counter
their contribution has been ignored. The ^{18}F source
prepared by the irradiation of Li_2O in the Harwell
using the successive reactions ^{6}Li (n, α) T and ^{16}O (T, n)
The purity was checked by following the decay for five h
lives. Weighed portions of the solution were counted in
4π counter and in the spectrometer and the resulting spec
meter efficiency was 5·00 ± 0·04%. The ^{22}Na source

ied by the Radiochemical Centre, Amersham. The 4π ter comparison resulted in a spectrometer efficiency for of 4·05 ± 0·08% and the efficiency correction factor Na was, therefore, 0·81 ± 0·02.

e calculated value of ω was 0·40. The simple absorption icients for 0·51 MeV and 1·28 MeV γ-rays in sodium e yield the efficiencies $\eta_1 = 0{\cdot}11$ and $\eta_2 = 0{\cdot}35$, but alue used for η_1 was increased to 0·20 to correct for the oelectric absorption of some of the Compton-scattered ys (see also the results of R. B. Owen quoted in Ref. 5). ratio η_3/η_1, obtained from the single channel spectrum Na, was 0·33. Since $E = 1$ for ^{22}Na, the correction r for this nuclide becomes:

$$1 - 0{\cdot}40[0{\cdot}70 - 0{\cdot}33\,(1 - 0{\cdot}20)] = 0{\cdot}83$$

estimated error limits of ±0·04, in good agreement the experimental value. The correction factor can thus stimated to within ±4% limits even for the comparison simple positron emitter with a one-for-one positron-γ- ter and using the maximum value of ω. If ω were reduced ve an overall efficiency of 2%, the error in the correction r would be ±1·5% which is less than the estimated error s of the 4π calibration (±3%). Furthermore, several rtant nuclides require no correction factor when com- d with a ^{22}Na standard, since they also have γ-rays of it the same energy in coincidence with all the positron itegrations.

GENERAL PERFORMANCE

ie aluminium annihilating plates are thick enough to e the discrimination against pure β-emitters complete, the degree of discrimination against γ-emitters depends he energy of the γ-rays. Nuclides emitting γ-rays of gy less than the lower level of the pulse analyser are pletely eliminated, provided that build-up of pulses in amplifier can be neglected. For nuclides emitting γ-rays ve this energy, however, discrimination is not complete iuse some Compton or photoelectric pulses are recorded ich channel and random coincidences may occur. There lso the possibility of true coincidences arising from the orption of γ-rays back-scattered into one crystal from a npton process in the other. These factors and the relative ortance of the energy selection and the coincidence selec- are illustrated by the response of the counter to ^{137}Cs ch is a β-emitter with a single 0·66 MeV γ-ray. Tests were le with a ^{137}Cs source of 10^5 disintegrations/min. Each nnel of the positron counter when set on the 0·51 MeV k (actual range 0·43 to 0·59 MeV) had an efficiency of for 0·51 MeV γ-rays and 1% for 0·66 MeV γ-rays. e positron annihilation results in two 0·51 MeV γ-rays, i channel acts as a simple spectrometer with an efficiency 16% for positrons and therefore a discrimination factor 16 against a ^{137}Cs background. The efficiency of the iplete coincidence system for positrons was 4% and only ounts/min were recorded as coincidences from ^{137}Cs. This n efficiency of 0·003%; that is, the coincidence system a discrimination factor of 1300 against a ^{137}Cs back- und. The ^{137}Cs coincidence counts are all true coin- nces arising from back-scattering, the contribution from dom coincidences being negligible at the counting rates of count per min per channel. The performance is very adversely affected by the omission of the pulse analysers. The ^{137}Cs efficiency then rose to 0·17% (170 counts/min, of which 6 counts/min were random coincidences arising from the $1{\cdot}4 \times 10^4$ counts per min per channel). The efficiency for positrons in these circumstances was 8%, giving a discrimination factor of only 47 against a ^{137}Cs background.

The response of the counter has also been measured for mixed fission products at eight and 76 hours after fission. Sources containing 2×10^7 and $3{\cdot}5 \times 10^8$ fissions respectively were produced by pile irradiations of uranyl nitrate. Mixed fission products give true coincidences from γ-ray cascades, particularly from ^{132}I, and many γ-rays of energy 0·5 MeV or greater are also present. The measured response of the positron counter using the weaker source at eight hours after fission was 10^{-6} coincidence counts per min per fission, all of which are true coincidences, since the single-channel rates of 1100 counts/min would give only 2×10^{-9} random coincidence counts per min per fission. A positron source of N disintegrations/min gave 4×10^{-2} N counts/min, and the permissible eight-hour fission product contamination to give a 10% background of coincidences from fission product γ-rays is therefore 4×10^3 N fissions. At seventy-six hours after fission the response using the stronger source was 3×10^{-8} coincidence counts per min per fission and 2×10^{-6} single-channel counts per min per fission, the contribution due to random coincidences again being negligibly small.

In general, the positron coincidences can be distinguished from true $\gamma - \gamma$ coincidences by a decay curve analysis. If a reduction in overall efficiency is acceptable, the selectivity can be improved by moving the crystals further apart, since the positron efficiency varies directly with the solid angle ω, while the unwanted coincidence effects vary as ω^2. The selectivity against random coincidence effects could be improved by improving the electronic stability so as to use a faster coincidence resolving time. There would be no advantage in replacing the sodium iodide crystals by fast organic scintillators, since the loss of energy selection would lead to a large increase in back-scatter coincidences.

ACKNOWLEDGEMENTS

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REFERENCES

(1) KENDALL, H. W., and DEUTSCH, M. *Phys. Rev.*, **93**, p. 932 (1954).

(2) DEBENEDETTI, S., and SIEGEL, R. *Phys. Rev.*, **85**, p. 371 (1952).

(3) BELL, R. E., and GRAHAM, R. L. *Phys. Rev.*, **90**, p. 644 (1953).

(4) PATE, B. D., and YAFFE, L. *Canad. J. Phys.*, **33**, p. 929 (1955).

(5) SHARPE, J. *Nuclear Radiation Detectors*, p. 84 (London: Methuen and Co. Ltd., 1955).

The use of a manometric densitometer for molten salts

By the late L. J. B. Husband, B.Sc.,* Imperial College of Science and Technology, London, S.W.7

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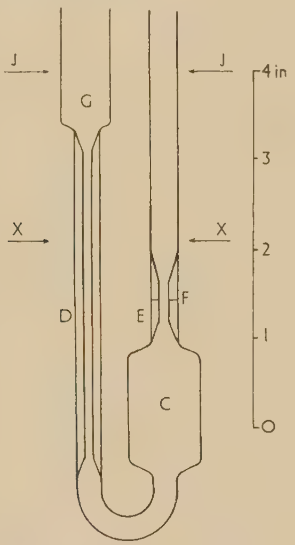
A manometric method of determining the density of a liquid is described. After calibration of the densitometer only remote observations need be made of a setting to a fiducial line and of the pressure of an applied gas. No confining fluid is used. This makes the densitometer particularly suitable for liquids at high temperatures. The densities of the following inorganic salts above their melting points have been found: sodium nitrite, potassium thiocyanate and potassium chlorate.

A densitometer is described in which a difference in height of two columns of a liquid is obtained by applying to one column a known pressure of a gas, so that this or the other column is at a fiducial mark. The measurement of gas pressure with a manometer and the observation at the fiducial mark together with a volume calibration are sufficient to give the liquid density.

The tendency of many molten salts to gaseous decomposition and to sublimation often excludes a dilatometric determination of their densities *in vacuo*; again, both their reactive nature and the high temperature exclude all known confining fluids. The densitometer described was constructed of Pyrex to contain the molten salt at atmospheric pressure, at temperatures up to 500° C.



Manometric densitometer

It is in the shape of a U with both ends open, and consists of limbs of uniform internal cross-section in which the difference of liquid heights takes place, with a bulb so that changes of density are magnified. When a measured pressure is applied to either side, the difference in liquid heights is inversely proportional to the liquid density ρ.

A fiducial line F is engraved on one limb of the densitometer, which is then calibrated (volume V_0) by mounting vertically and filling with water or mercury to the level of the fiducial line, and the added mass is found by difference. In use the dilatometer is filled with molten salt of volume V so that $|V - V_0| < AH/4$, A being the cross-sectional area of the second limb and H its length.

Let the pressure needed to bring one liquid meniscus the fiducial line be P and the difference of liquid heig be h; let the mass of salt be M, then

$$P = h\rho g = |V - V_0|\rho g/A = |Mg/A - V_0\rho g/A|$$

ρ may thus be found from P, M, V_0 and A. Of these, the only dependent variable. Hence only a remote obse tion has to be made of the densitometer. The pressur obtained from a manometer containing, in our case, a liq of density lower than that of the investigated liquid; so t its changes in volume are proportionately more accurat measured than by any direct method.

THEORY OF THE METHOD

The condition when a pressure P is applied above the capillary will be examined.

$$P = h\rho g$$
$$\rho = M/V$$
$$V = V_0 - Ah$$

h need not be determined experimentally, since h and ρ obtained by successive approximations as follows (subscri indicating the order of approximation).

Let $\rho_1 = M/V_0$

From (1) $h_1 = P/\rho_1 g$

then $\rho_2 = M/(V_0 - Ah_1) = M/(V_0 - AP/\rho_1 g)$

$h_2 = P/\rho_2 g$

$\rho_3 = M/[(V_0 - AP/\rho_2 g)] =$

$= M/\{V_0[1 - AP/Mg + (AP/Mg$

In general $\rho_n = M/\{V_0[1 - AP/Mg + (AP/Mg)^2 -$

$- (AP/Mg)^3 + \ldots (-AP'/Mg)^{n-}$

where $n > 4$.

If P is applied to the short capillary then

$$\rho_n = M/\{V_0[1 + AP/Mg + (AP/Mg)^2 + + (AP/Mg)^3 + \ldots (AP/Mg)^{n-}$$

where $n > 4$

If Ah is $V_0/100$ then ρ_3 differs from ρ_2 by only 0·01% a this is less than the experimental error.

EXPERIMENTAL SECTION

Calibration and procedure. C is a bulb of 20 ml. capaci D and E are capillary tubes (1·50 ± 0·01 mm) respectiv about 10 and 2 cm long); F is the fiducial line.

The weighed (±25 μg) densitometer is immersed to t approximate level XX with D vertical in a thermostat water bath (±0·05° C) and is filled with distilled water the fiducial line at ten temperatures between 20° C and 50°

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* Mr. Husband died on 31 October, 1957, after completing this paper in draft; it was revised for publication by Prof. A. R. Ubbelohde.

th capillaries must be of equal internal diameter to re equal capillary attractions: they were cut from the piece of Veridia capillary tube (Chance Bros. Ltd.).

he densitometer used (previously thoroughly cleaned by oiling mixture of nitric and sulphuric acids) the water s, viewed horizontally, differed by about 1 mm and made equal by application of pressure. The mass of r was adjusted by addition or withdrawal, until both s were in the horizontal plane containing the fiducial line.

he densitometer, thus filled with water, was re-hed (±25 μg) from which the mass of water was known 0 μg).

om the mass of water and its specific volume (obtained tables) was found the volume of water which filled the itometer at each temperature. A straight line was fitted he points, by the method of least squares, to give the me (±0·01%) at a standard temperature (25° C). umes (±0·02%) at higher temperatures were calculated the thermal expansion coefficient of Pyrex (linear = ± 0·14 × 10^{-6}/per° C).

he internal diameter of the long capillary was found by hing measured lengths of mercury thread placed inside.

MEASUREMENT OF DENSITIES OF SALT MELT

bath containing 5 l. of a melt of alkali–metal nitrates nitrites was thermostated (±0·05° C) between 155° C 470° C.

he densitometer was immersed vertically to the level *JJ*. he present experiments the fiducial line was well illuminated in the focal plane of a low-power microscope. For ds where opaque containers are essential a fine wire nted axially in the capillary and carrying a high frequency nating potential relative to the salt would be suitable as ucial mark.

he salt, as melt, was fed into *G*, sufficient to fill the itometer approximately to the fiducial line. A constant pressure ($\leqslant 5 \times 10^4 \pm 4$ dyn/cm^2), measured with a dibutylphthalate manometer, of dry air or any non-reacting gas was applied to bring the meniscus to the fiducial line. The connexion was gas-tight.

The pressures were measured for both a rising and a falling meniscus to reach the fiducial line. For one salt (KSCN) the difference in these pressures accounted for one-third of the total error in ρ (0·04–0·05%); for another salt ($NaNO_2$), however, no significant difference in pressures was found, and the total error in ρ was 0·03%. The temperature range for a given mass of melt is determined by its volume change with temperature and the volume of the long capillary; the range is increased by addition or withdrawal of weighed amounts of melt.

The density of dibutylphthalate, between 10° C and 26° C, had been previously found in the densitometer; the manometer was contained in a water bath and was unaffected by ambient temperature fluctuations.

RESULTS

By way of illustration, the following densities have been measured for ionic melts near their freezing points, t_f(ρ in g/ml.; t in ° C):

sodium nitrite melt

$$\rho = 1{\cdot}8202 \pm 0{\cdot}0004 - 0{\cdot}000\,69(t - t_f) \qquad t_f = 271{\cdot}0$$

potassium thiocyanate melt

$$\rho = 1{\cdot}6005 \pm 0{\cdot}0007 - 0{\cdot}000\,80(t - t_f) \qquad t_f = 173{\cdot}5$$

potassium chlorate melt

$$\rho = 1{\cdot}9550 \pm 0{\cdot}0004 - 0{\cdot}000\,67(t - t_f) \qquad t_f = 356{\cdot}0$$

dibutylphthalate used in the manometer

$$\rho = 1{\cdot}0470 \pm 0{\cdot}0002 - 0{\cdot}000\,81(t - 19) \qquad 19 \leqslant t \leqslant 26$$

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he preparation of powder specimens from active and toxic metals for use in conventional X-ray diffraction studies

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[*Paper first received* 17 *March and in final form* 22 *April*, 1958]

An argon dry box and an associated procedure is described for the preparation of specimens for use in Debye–Scherrer powder cameras at high and low temperatures. Special features allow filings to be annealed at >1200° C, and quenched, if necessary, in vacuo: there is no need for fiilings to be sealed in a container for this purpose. Filings can be sealed in silica quills (~0·025 in. o. diameter and wall thickness ~0·005 in.) for use as specimen, by a small electrical furnace.

The dry box is designed to enable an operator to be fully protected and to have fine control over the specimen at all stages of its preparation.

1. INTRODUCTION

preparation of metal powder specimens in the form of rods, approximately 0·020 in. diameter for use in X-ray action studies involves three distinct operations:

) preparation of powder, usually as metal filings;
) annealing to remove strains introduced into the filings by the method of preparation; and
) fabrication of a thin rod from annealed powder.

or studies at room temperature thin rods may effectively roduced by supporting the powder in a gum on a fine silica rod or by binding the powder to form a solid rod with gum tragacanth. It may even be possible to sinter a large amount of powder and to machine a fine rod from the resultant fine-grained material. These methods, however, suffer severe disadvantages. In the first two cases the specimens are not suitable for high temperature studies while in the latter it is necessary to have, initially, a large amount of metal filings. These difficulties are usually overcome by using powder contained in a fine silica quill which may be sealed under vacuum or an inert atmosphere. Even this method, however, is not entirely satisfactory as it is limited in high temperature studies by chemical attack between the metal filings and silica. Such attack is not common below 500° C and the method is frequently used up to 1000° C.

In sampling toxic and active metals it is necessary to isolate the powder from the atmosphere at all stages of its preparation and exposure to X-ray radiation. In these cases, therefore, the third stage of specimen preparation, (*c*), may be written:

(*c*′) deposition and sealing of powder in fine silica quills under vacuum or in an inert atmosphere.

A procedure has recently been developed which enables the three operations (*a*), (*b*) and (*c*′) to be carried out in a single argon dry box. It is the design of this dry box and general procedure which is described in this paper. Special features enable:

(i) the specimen to be handled easily at all stages of its preparation,
(ii) filings to be annealed in vacuo or argon without prior sealing in a glass or silica tube, and
(iii) the silica quill, containing annealed filings, to be sealed under vacuo by electrical heating.

2. DRY BOX

2.1. *General*

The general layout of the dry box is shown in Fig. 1. The overall dimensions of the box are $7\frac{1}{2} \times 5\frac{1}{2} \times 2$ ft. Three working zones of equal volume project from the front of the box in each of which are carried out one of the three operations (*a*), (*b*), and (*c*′) (see section 1).

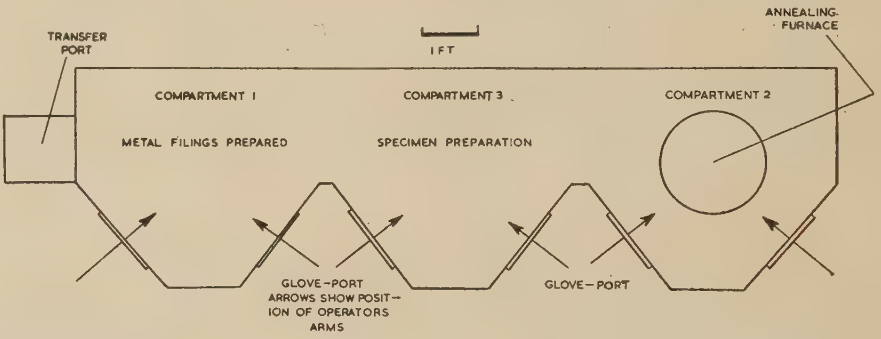

Fig. 1. General layout of dry box

The top and side faces of each projection are angled at 60° and 45°, respectively, to the front of the box. The top of the box and the sloping top to each compartment is made of Perspex; glove ports are housed in the sides of each projection. Each projection is, therefore, accommodated in the lap of a seated operator. This arrangement allows specimens to be handled and viewed in each compartment from a natural working position and is very necessary if limited amounts of sample and small fragile specimens are to be prepared quickly and without fatigue. Facilities are provided for making approximately two changes of argon per hour and for sampling, by a glow discharge, the incoming and outgoing atmosphere for oxygen. The box contains a single transfer port and a mains terminal board (250 V). All the services, water, electrical power and vacuum which are incorporated in the box are controlled from outside the box. It may prove desirable, if several ancillary components are needed either for general maintenance or for specimen preparation, to position a magnetic tool board on the back surface of the box. Such a board has two advantages: (*a*) it provides for a large open working area on the floor of the box, yet (*b*) facilitates ready positioning and removal of tools by gloved hands.

2.2. *Preparation of filings*

The preparation of filings follows the conventional p cedure and is carried out in compartment 1, see Fig. 1. metal may be held in a vice and the filings collected i tray or the metal rubbed over a file submerged in a ff medium as is necessary in the preparation of pyropho materials or filing at temperatures below 20° C. After filings have been dried and sieved a suitable quantity, appro mately $0\cdot25$ cm^3 is placed into a small inert metal (tantalu crucible, 1 in. long × $0\cdot25$ in. diameter and the unit is tra ferred to compartment 2, see Fig. 1, where annealing may carried out. All these operations are executed without worker changing his initial seated position.

2.3. *Annealing of filings*

2.3.1. *The furnace.* The furnace unit, which is sho schematically in Fig. 2, is contained in compartment 2 of dry box. This arrangement is not ideal as it does not per a continuous flow in the procedure of operations neede the preparation of a specimen: it would be an improvem to put the annealing furnace in the centre compartment. unit consists, essentially of a single tantalum heating elem *E* in the form of a split cylinder $1\frac{1}{4}$ in. long × ½ diameter × $0\cdot010$ in. and supported in the centre o cylindrical zone, of outer dimensions $3\frac{1}{2}$ in. long × 3 diameter comprised of one platinum radiation shield adjac to the heating element and six tantalum radiation shields *T*; top and bottom of this insulating zone may be swung asid allow the furnace to be charged, and in turn for the charge be dropped instantaneously from the furnace into a quench medium. The furnace zone is carried on a stainless st base plate *B*, 10 in. diameter on which rests a Pyrex gl bell-jar *G*.

The base plate also carries the necessary standard electri connexions for the supply of the furnace power *FP* and for necessary thermocouple leads *TP*; a 2 in. diameter co nexion is made through the base plate to an oil diffusion pu housed beneath the dry box. Also extending through base plate is the shaft, *S*, which controls the movement of radiation shields, together with two rotatable shafts *F* each with a combined movement of 4 in. along their a To allow these shafts to be controlled by hand from wit the dry box, the furnace base plate stands 6 in. above floor of the dry box. Extensions to the two shafts provide the means for manoeuvring a "getter" in and of the furnace zone and for the subsequent insertion of crucible containing the specimen filings, respectively.

The glass bell-jar is waxed into a stainless steel annu which seats on an O-ring vacuum seal: the envelope counter-balanced so that it may be easily raised or lowe by gloved hands. There is no reason why the glass envelc should not locate directly on to an O-ring and there nize the amount or organic and volatile matter in the ice chamber.

general, filings are allowed to furnace cool after annealing is possible to quench the crucible and filings. Normally rucible is supported in the furnace by a wire loop running igh a rigid hook, *H*, above the radiation shields. If, ever, this hook is attached to its supporting arm by a length of 5 A fuse wire then by fusing this link the ble will fall under gravity into a silicone oil bath beneath oottom radiation shield: it is of course, necessary to the radiation shield away from the furnace zone prior ienching. This fuse may be blown when the supporting is at a few volts potential with respect to earth and the is shorted to earth by surface contact with one of the ipulators *R*.

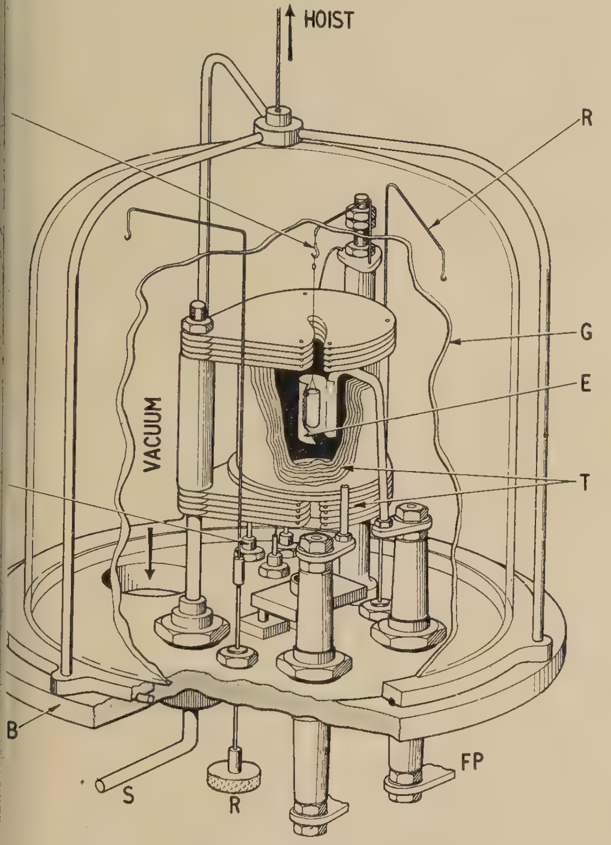

Fig. 2. Schematic diagram of furnace unit

he furnace has operated successfully up to 1200° C with a ace current of 60 A at 35 V. A thermocouple placed in ummy crucible has been used to calibrate the thermal acteristics of the furnace against applied voltage. With icuum of 5×10^{-5} cm of mercury the temperature of glass envelope is raised by 30° C in $\frac{3}{4}$ h. This introduces langer: in most cases, however, where annealing times are roximately 5 min, there is a negligible rise in temperature he bell-jar and consequently there is no need to provide er cooling in the active zone.

he thermal characteristics of the furnace are excellent. ting at 20° C the crucible temperature can be raised to)° C in 3 min: the outgassing procedure is minimized by absence of any porous insulator in the furnace zone a vacuum of 5×10^{-5} cm of mercury can be obtained in 2 h of charging the furnace. At all times the movet and condition of the specimen filings can be observed.

2.3.2. *The procedure.* With the bell-jar in the raised position a small titanium helix is suspended in the furnace zone from the hook *H*: the crucible, containing the metal filings, is placed on the arm of one of the manipulators. After evacuation by normal pumping procedure the remaining atmosphere in the furnace may be gettered by raising the temperature of the titanium helix. Subsequently the getter may be removed from the furnace zone and replaced by the crucible: the top and bottom radiation shields are in position during heating. After annealing the crucible can be either furnace cooled or quenched.

2.4. *Preparation of the X-ray specimen*

The filings, after suitable cleaning if contaminated by oil from the quenching bath, are fed into a small sealed tube 1 in. long × 0·2 in. diameter with a taper at the sealed end. Filings may be transferred from this tube into a length of silica quill, 0·025 in. o. diameter and 0·005 in. wall thickness, and sealed at one end, by inserting and twisting the open end of the quill into the filings resting in the tapered constriction. Not many filings are transferred in one operation but the quantity that is may be pushed down the silica quill towards the closed end by a silica rod. Normally a 0·2 in. length of filings in the quill is adequate. The quill is now sealed under vacuum, or a partial pressure of an inert gas. This procedure is illustrated in Fig. 3, and is carried out in compartment 3 of the dry box.

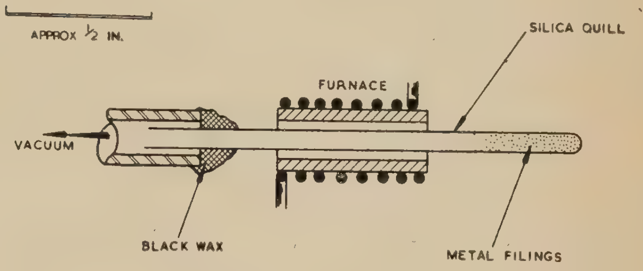

Fig. 3. Arrangement for sealing filings in silica quill

The quill is fed through a small furnace 0·5 in. long × × 0·1 in. o. diameter and sealed into a vacuum line by black wax: this wax is melted and formed by a small electric soldering iron. The furnace is made from 14 turns of 0·020 in. diameter platinum wire wound on a fine alumina thermocouple sheath 0·035 in. i. diameter, 0·045 in. o. diameter. With the furnace temperature just below the melting point of platinum (1774°C) it is found that the evacuated silica quill may be sealed by slowly drawing the free end of the quill from the furnace. The heat source is sufficiently localized not to risk damage to gloves or to be regarded as a fire hazard. It is imperative to use an alumina furnace lining as otherwise the quill is embrittled, presumably by complex silicates and, therefore, cannot be handled. The use of a small electrical furnace for sealing silica quills is a notable advance on current techniques: gas and arc welding cannot be used in active boxes operating under perfect conditions. Carbon arcs have been used in air or impure argon boxes but in general such arcs are found to be unstable in argon atmospheres.

3. ACKNOWLEDGEMENT

It is a pleasure to acknowledge many helpful discussions with Mr. A. J. Marriott during the initial development of the dry box.

Photoelectric indicator for precision setting in co-ordinate measurements

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Precision measurements of co-ordinates on photographic plates are tedious and tiring with ordinary microscopes with a visual setting. The present electronic indicator presents the intensity in the line or point to be measured as mirror images on an oscilloscope and uses the traces as coincidence marks. Measurements can be made in two co-ordinate directions with a standard deviation of $0\cdot3\ \mu$ or better for the setting on a line or point.

INTRODUCTION

High precision measurements of length differences in one or two co-ordinates with a reproducibility of some tenths of a micron are tedious and very difficult with a visual setting in an ordinary high-powered microscope. Many factors influence the precision of the setting, especially the asymmetry of the lines or points to be measured. A visual setting on such a line with a microscope equipped with a double or other type of cross hair will not in many cases give the maximum as the correct setting point. When judging the position of highest density or illumination, the eye does not perceive the maximum value but the differences in intensity as it is more sensitive to that. In this case setting with an electronic device that shows a photometered curve of the intensity of the line or point has many advantages. It is possible to choose the peak or midpoint at the half-width as the correct setting position and to study the shape of the line in detail. Asymmetrical lines are very common on photographic plates from camera tests, for example, when a test figure consisting of a well-known square-net is photographed with a camera in order to determine the distortion of the lens. The asymmetry is due in this case to coma and astigmatism.

Photoelectric setting devices have been described by several authors.(1–4) Our main purpose is to obtain high-precision measurements of co-ordinates on photographic test plates where visual setting with ordinary microscopes is not sufficiently accurate. The present photo-electric indicator is a modification of the one built by Tomkins and Fred.(3)

DESCRIPTION OF THE SETTING DEVICE

The optical components are shown schematically in Fig. 1. The plate *Pl* to be measured is illuminated by an ordinary system consisting of a lamp and condenser lenses. A microscope objective L_3 gives an image of an area of the plate *Pl* on the slit *Sl* in front of the photo-multiplier tube and on the screen *Sc* used for visual inspection. The magnification at the slit *Sl* is 25 times. Several semi-reflecting and ordinary mirrors are placed in the light path. There are also two image-turning prisms D_1 and D_2, so that lines along the two co-ordinate directions can be set parallel with the slit. The slit can only be turned a few degrees around an axis perpendicular to the jaws. The width of the slit can be varied between 15 and 500 μ which corresponds to $0\cdot6$–$20\ \mu$ on the plate *Pl*. The width is always choosen so that it is a fraction of the line image; it was usually 50 μ. The length of the slit can be varied with a "fish-tail" mask.

The light through the image-turning prisms is slightly convergent so that the prisms cause a small aberration which, however, does not influence the setting precisions. We can measure in the two directions by blocking the light through the prism D_1 or D_2 by means of the two coupled shutters *Sh* (Fig. 1). The shift between the co-ordinates could have been made by rotating prism D_1 through but this might change the coincidence position if the rota is not always of the same amount. Such errors are avo by using two prisms and shutters.

Our electrical indicator system is of similar kind to used by Tomkins and Fred.(3) The octagonal prism rotated by a synchronous motor at a speed of 1500 rev/r Alternate faces of the prism are blacked so that the ph multiplier Ph_1 receives 100 pulses per second. The out from the photo-multiplier is coupled to the *y*-deflexion o ordinary oscilloscope, and the *x*-deflexion is a 50 c/s s wave. The pulses that represent the intensity in the line thus shown double on the oscilloscope screen and the traces are mirror images. When the plate *Pl* is moved, two traces move over the screen. As a mark for cor setting one can choose the coincidence of the maxima, points at the half-width or some other suitable point on

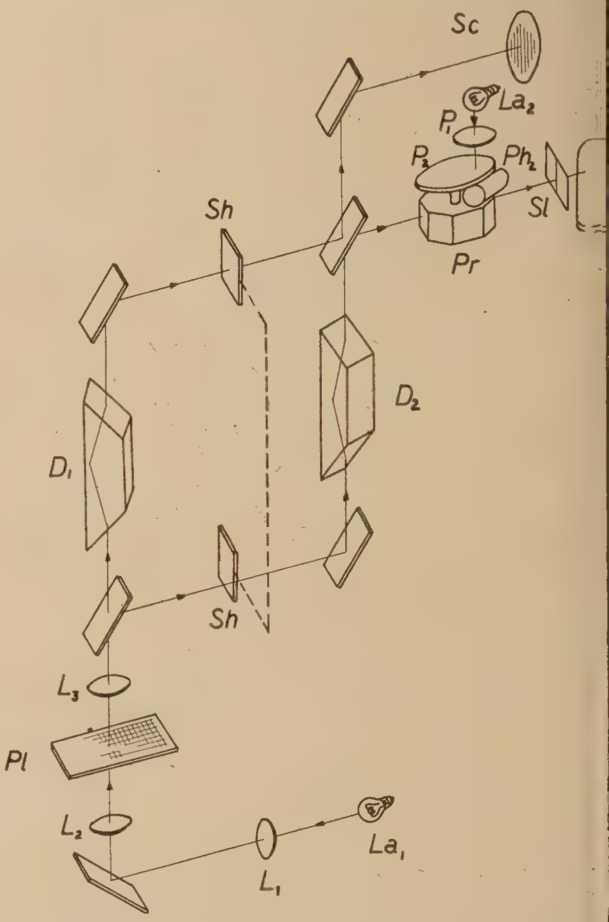
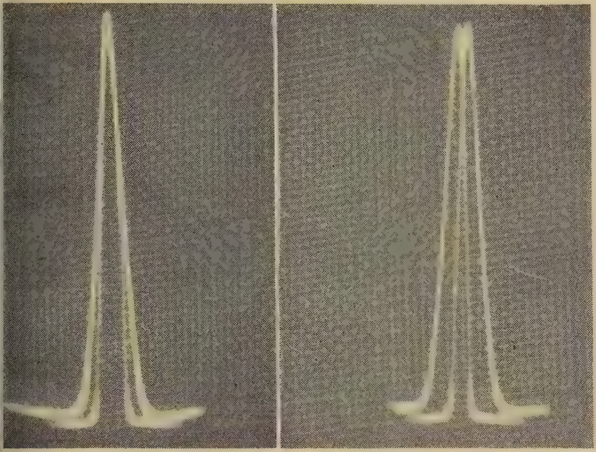


Fig. 1. Optical layout of the comparator system

traces (Fig. 2). There is a mark on the screen *Sc* which sponds to the correct setting with the electronic device hat a rough setting can be made visually.



g. 2. Oscilloscope traces (*a*) at coincidence; (*b*) 3 μ from coincidence

ie precision of the setting device depends on the syn-nization of the horizontal sweep voltage in the oscillo-e with the rotation of the prism *Pr*. If the mechanical ion and electrical phase shift relatively to each other in motor, the traces on the screen will change. We first . the voltage from the same line to the motor and the p. During the warming-up time, about 5 min, a slight detectable change was observed between the electrical mechanical phases in the motor. The rotating masses t be carefully balanced otherwise a doubling of each e will occur, due to a non-uniform angular velocity of motor's rotation. This system worked well, but sudden nges in the line voltage rendered the coincidence point a uncertain, and it was therefore felt that a stronger pling between the two voltages to the oscilloscope was rable. The horizontal deflexion voltage is now taken a system with a lamp, a rotatable Polaroid film P_1 on lamp housing, a rotating Polaroid P_2 fixed to the gonal prism *Pr* and a vacuum photocell Ph_2. When P_2 is rotated with the prism *Pr* a sinusoidal 50 c/s wave is obtained from Ph_2 to the horizontal deflexion instead of the main 50 c/s line voltage. Our first test with this system showed a doubling of all traces, which was not due to the above-mentioned unbalance. It depended on the fact that a small part near the periphery of the rotating Polaroid was used and the polarizing properties of the film cemented between the two glasses were not exactly equal when turned through 180°. The lines of equal polarization seemed to be slightly curved. The doubling was removed by blacking half of the Polaroid P_2 so that every second period of the signal from Ph_2 was zero. Only half of the pulses from the photocell Ph_1 are thus seen on the oscilloscope screen, i.e. two pulses appear, the next two not and so on. By rotating the Polaroid P_1 the phase difference between the signals from the photocells Ph_1 and Ph_2 can be changed so that the pulses from Ph_1 are seen in a suitable position on the oscilloscope screen.

All lamps are fed by d.c. from accumulators in order to avoid 100 c/s ripple from the line and intensity changes during the measurement of a plate.

CONCLUSIONS

The setting on lines and points with the equipment is faster and less tiring than with microscopes. It also gives a higher accuracy and affords valuable information about the line shape. Fig. 2 shows pictures of the oscilloscope screen when the line coincides and when it is 3 μ from coincidence. The setting on an individual line has proved to have a standard deviation of 0·3 μ. With the existing set-up the precision is limited by the mechanical properties of the co-ordinate table.

REFERENCES

(1) Rymer, T. B., and Halliday, J. S. *J. Sci. Instrum.*, **27**, p. 50 (1950).

(2) Fürth, R., and Oliphant, W. D. *J. Sci. Instrum.*, **25**, p. 289 (1948).

(3) Tomkins, F. S., and Fred, M. *J. Opt. Soc. Amer.*, **41**, p. 641 (1951).

(4) Pamphlet *Photoelectric microscopes for comparators* (Geneva: Soc. Genevoise d'Instruments de Physique, 1956).

Laboratory and workshop notes

use of coarse gratings to find the refractive index of liquids

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[*Note received* 25 *February*, 1958]

owing on our note published on p. 464 of the November 7 issue of this *Journal*, we wish to report an alternative method for finding the refractive index of liquids using a pair of coarse gratings. According to the method described in the previous note, two sets of observations have to be taken, the first with the empty cell and the second with the liquid in the cell; in each case the number of bands that are displaced and the corresponding angles of incidence have to be noted. If *n* bands get displaced due to the cell alone and

Table 1. *Change in band shift with angle of incidence*

Liquid used, water at 25° C. Internal width of the cell, 1·004 cm.

	Shift no. of bands				
Angle of incidence *i*	*Empty cell* *n**	*Liquid and cell* *m*	*Liquid alone* *m − n = r*	*Displacement due to the liquid* *r*Δ	*Refractive index* μ
22° 24′ 30″	4·68	20	15·32	15·32 Δ	1·332
27° 9′ 30″	5·73	25	19·27	19·27 Δ	1·334
31° 25′ 30″	6·80	30	23·20	23·20 Δ	1·336
35° 30′ 0″	7·83	35	27·17	27·17 Δ	1·333
				Mean	1·3337

* The exact value of *n* is found from a graph representing *i* and *n*.

m bands due to the cell and liquid together for a given angle of incidence *i*, the shift due to liquid alone is $m - n = r$.

Typical observations are given in Table 1; the liquid chosen is water at 25° C and its refractive index is calculated using the formula

$$r\Delta = t \sin i \left[1 - \sqrt{\left(\frac{1 - \sin^2 i}{\mu^2 - \sin^2 i}\right)}\right] \qquad (1)$$

where Δ is the grating element, *t* the internal width of the cell and μ the refractive index of the liquid.

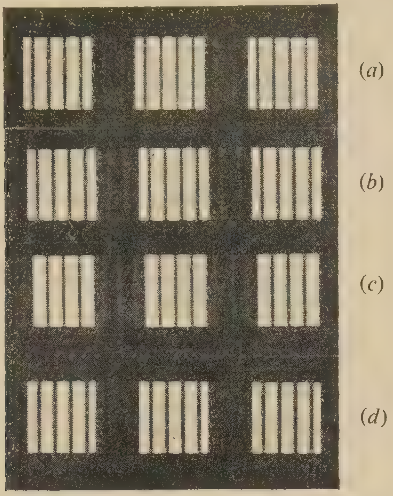

Fig. 1. Variation of visibility of bands with the angle of incidence using one liquid

Angle of incidence: (*a*) 0; (*b*) 2° 53′; (*c*) 5° 46′; (*d*) 8° 39′.

Table 2. *Angle of incidence at which the bands appear sharp and clear*

Standard liquid, water at 25° C. μ_2, 1·333

Reading of prism table		*Difference*	*Angle of incidence*		*Refractive index*
Clockwise	*Anticlockwise*	2*i*	*i*	$m_2 \sim m_1 = r$	*of liquid, B*
68° 11′	56° 39′	11° 32′	5° 46′	1	1·467
73° 58′	50° 54′	23° 4′	11° 32′	2	1·466
79° 44′	44° 59′	34° 35′	17° 18′	3	1·466
85° 40′	39° 5′	46° 44′	23° 22′	4	1·464
91° 25′	33° 23′	58° 2′	29° 1′	5	1·464
				Mean	1·4654

The appearance of the system of bands as the angle of incidence is varied can be seen from Fig. 1, visibility remaining practically unaltered.

Let us take two different immiscible liquids *A* and *B* in the optical cell, *B* filling the bottom half of the cell and *A* the upper half. On examination, the bands appear clear and sharp only at certain discrete angles of incidence as illustrated in Fig. 2. These angles of incidence at which the bands are clear are given in Table 2, for the liquids water and carbon tetrachloride. At normal incidence, the bands are obviously clear, for there is no lateral displacement of the rays. At an angle of incidence *i*, the lower half of the beam which passes through liquid *B* undergoes a lateral displacement $(n + m_1)\Delta$; while the upper half of the beam which passes through *A* undergoes a lateral displacement $(n + m_2)\Delta$ where $n\Delta$ is the displacement due to the cell alone.

A system of bands is formed by each half of the original beam. Only when the two systems of bands coincide will the bands as a whole appear clear and sharp, and the condition for the two systems of bands to coincide is

$$(n + m_1)\Delta \sim (n + m_2)\Delta = r\Delta$$

or

$$(m_1 \sim m_2)\Delta = r\Delta$$

where *r* is an integer including zero. The bands will apr clear at successive angles of incidence i_0, i_1, i_2, . . . for w *r* is 0, 1, 2 . . . respectively.

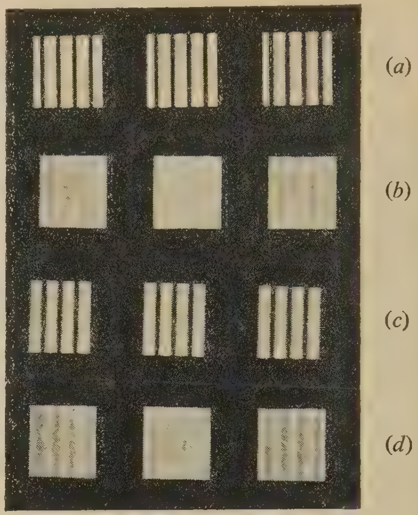

Fig. 2. As Fig. 1 but using two liquids, water ar carbon tetrachloride

Now $$m_1\Delta = t \sin i \left[1 - \sqrt{\left(\frac{1 - \sin^2 i}{\mu_1^2 - \sin^2 i}\right)}\right]$$

and $$m_2\Delta = t \sin i \left[1 - \sqrt{\left(\frac{1 - \sin^2 i}{\mu_2^2 - \sin^2 i}\right)}\right]$$

Hence

$$(m_1 - m_2)\Delta = r\Delta = t \sin i[\sqrt{(1 - \sin^2 i)}]\left[\frac{1}{\sqrt{(\mu_2^2 - \sin^2 i)}} - \frac{1}{\sqrt{(\mu_1^2 - \sin^2 i)}}\right]$$

$$= \frac{t \sin 2i}{2}\left[\frac{1}{\sqrt{(\mu_2^2 - \sin^2 i)}} - \frac{1}{\sqrt{(\mu_1^2 - \sin^2 i)}}\right]$$

Using these discrete values of the angles of incidence, refractive index of liquid *B*, namely μ_1, may be calcul knowing the refractive index μ_2 of the liquid *A* whic taken as standard.

This visibility method is superior to the band shift meth firstly because the shift of the band due to the cell is elimina and secondly because the actual shift of the bands does have to be noted.

Inventoried storage of large numbers of small radioactive particles

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ote first received 1 *May*, 1956, *and in final form* 20 *March*, 1958]

need for a special shielding device and record system for hot, small, metal particles was noted in certain work in laboratory. This involved small metal samples of radio- e tungsten, chromium and gold which had been activated he Oak Ridge Pile. These pieces of metal varied in ity from 10 mc/g to 10 c/g and weighed from 1 to 100 mg. requirements for storage of these pieces of metal were le. First, they were to be kept separate; second, they to be quickly and individually available, with a minimum anipulation and dosage to the worker; third, they had e well shielded; and fourth, a simple record system was ired for the many pieces which were to go into the age system. This record was to provide a rapid scheme the location and removal of any one of several hundred es.

udy of the available shielding for this type of storage ved that no simple device was currently available for inventoried handling of large numbers of radioactive erial. Thus, a method had to be developed and a lding system fabricated to solve this problem as follows.

record system for the many small particles is organized he basis of rectangular shielding modules, each of which ain six drawers. Each shielding box, rectangular in e, is complete with a sliding "tunnel" shield which les the worker to open a single drawer at a time without g any shielding effect. The box-like shield has 1 in. of on all sides as has the front of each drawer (Fig. 1). n these individual shields are stacked, the levels (*L*), 2, are designated *A*, *B*, *C*, etc., depending upon their position. The drawers (*D*) are numbered from 1 to 6 for each unit. Each drawer may have up to twenty receptacles, and the receptacles (*S*) are numbered from 1 to 120 for each shielding unit. Since the units are complete, they may be stacked to any height, depending on the number of radioactive items to be stored.

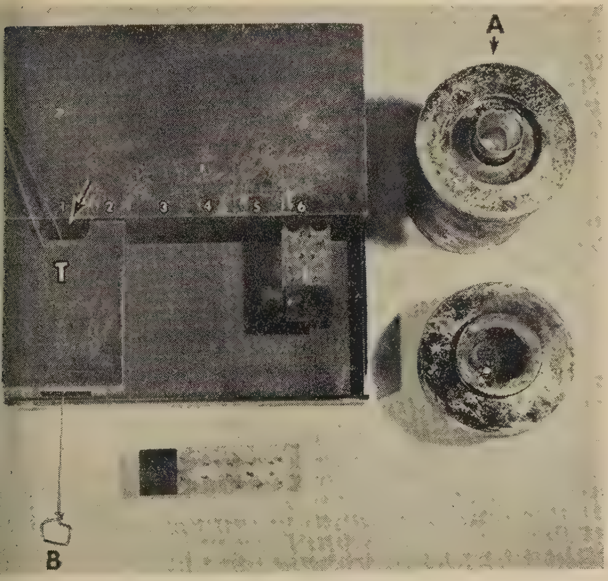

Fig. 1. Illustration of a single shielding unit

hese drawers are fitted with ten receptacles for large pieces, ather than the twenty small openings described in the text. he "tunnel" *T* is in position to load or unload drawer 1, (*D*1). se of the tunnel provides shielding for all but those radio- ctive materials in the receptacles which are being unloaded. he loading port is designated by the arrow. The draw bar *B* moves the drawer into the tunnel.

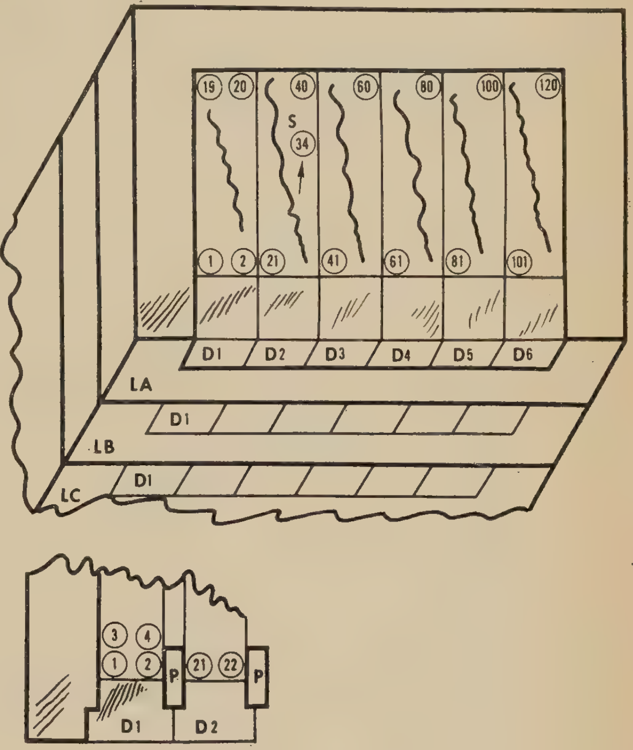

Fig. 2. Schematic diagram of the recording system for the shielding units

A particle stored in the first level (*L*), in the second drawer (*D*) the twelfth receptacle (*S*) in *that* drawer, would be designated in the records by the number *LA*-*D*2-*S*34 (arrow). The last two values overlap and obviate certain recording errors between drawers. Assuming that this is a particle of ^{51}Cr of 50 mg weight plus 2 mc activity, the full record will be: ^{51}Cr — 50 mg–2 mc-(LA-*D*2-*S*34).

The insert shows a recommended method for shielding at the drawer face by a system of stops *P*. This eliminates the need for precise, expensive machining. The modules were made of lead (shaded regions) with lucite drawers.

Let us assume that a bank of five units is stacked, and, in the second level, (*LB*), a hot metal particle is stored in the 4th drawer (*D*4) in the 79th cavity (*S*79) in the drawer system. The recording of the radioactive material in this position is as follows: *LB*-*D*4-*S*79 (Fig. 1). This recording enables the worker to obtain the piece in question immediately without unnecessary exposure to the other radioactive particles. The use of the tunnel aids in the reduction of the dosage when the drawer is open. An example of the full recording of data for a piece of gold foil with specific activity of 5 mc/mg in the position above would be: ^{198}Au –39·12 mg–195 mc–(*LB*-*D*4-*S*79). The samples may be kept in drawers or units according to specific activity, or sample weight, etc.

This modular system of shielding and record-keeping has been in use in this laboratory for about two years and has proved convenient and flexible. The radiation dosage to the workers using these particles has been reduced significantly.

A metal through glass seal

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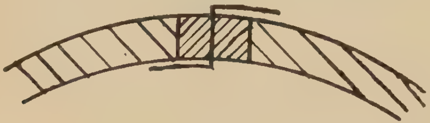
In the course of experimental work requiring a fairly large number of separate metal seals through a borosilicate glass (e.g. Pyrex) envelope, conventional tungsten seals have proved clumsy and unreliable. The requirement was for a reliable seal which need have only a small current carrying capacity but should be as flush with the glass surfaces, more especially the inner surface, as possible.

The seal developed for this purpose is based on the Houskeeper technique* which relies on the elasticity of both glass and metal used, to compensate for their widely different coefficients of expansion. It consists of a length of platinum tape (typically 0·5 × 0·04 × 0·0003 in.) sheathed by a short length of glass, and sealed through a small hole in the appropriate place in the wall of the vacuum tube. The resultant seal has a section as shown in the figure, when the free ends of the tape have been smoothed down on to the hot glass, thus avoiding both internal and external projections, which are undesirable as they may lead to breakdown at high voltages, especially in presence of agents such as caesium. Width and thickness do not appear to be critical at least within the ranges 0·03 to 0·06 in. and 0·0003 to 0·0006 in. respectively.



A section through a platinum tape seal

A large number of seals of this type have been made, of which only a small proportion have shown a detectable leak. Experiments indicate that such seals may also be made through Kodial glass (by Plowden and Thompson Ltd.). As the platinum tape seal relies on its extreme thinness rather than on any attempt at matching coefficients, it can probably be assumed that the seal can be successfully formed through any glass intermediate between Pyrex and the typical soft glasses through which it has been the practice to seal platinum for many years.

Platinum tape seals have successfully withstood thermal shock treatment involving sudden cooling to liquid air temperature from room temperature.

In view of the extreme thinness of the platinum tape some care is needed to confine the flame to the glass during the manufacture of the seal, as otherwise the tape may "burn off," leaving only a short stub projecting from the glass wall. Connexion can be made, however, even to this, with the aid of metallic paste. This difficulty would probably be accentuated were a lower melting point, or more easily oxidizable metal foil to be used.

Effective internal connexion may be made by evaporating a metallic coating directly on to the platinum tape. Alternatively a conducting metallic paint, or Aquadag (by Acheson Colloids Ltd.) may be applied. External contact may be made by coating the area around the seal with suitable silver paste to which a soldered or sprung contact may be made.

Although an expensive metal, platinum, is used, the amo per seal is so small that it costs approximately one per This is probably small compared with the cost of the lab involved.

Such seals using the thicker (0·0006 in.) tapes thro Pyrex glass appear to stand up to about 10 A before burn out, so that they should probably be quite safely usable, currents up to say 1·0 A. The 0·0003 in. tapes will approximately half this current safely.

Platinum tape seals should be very useful in tubes whe large number of reliable seals through borosilicate glas required. The current that can be carried should be q adequate for many applications.

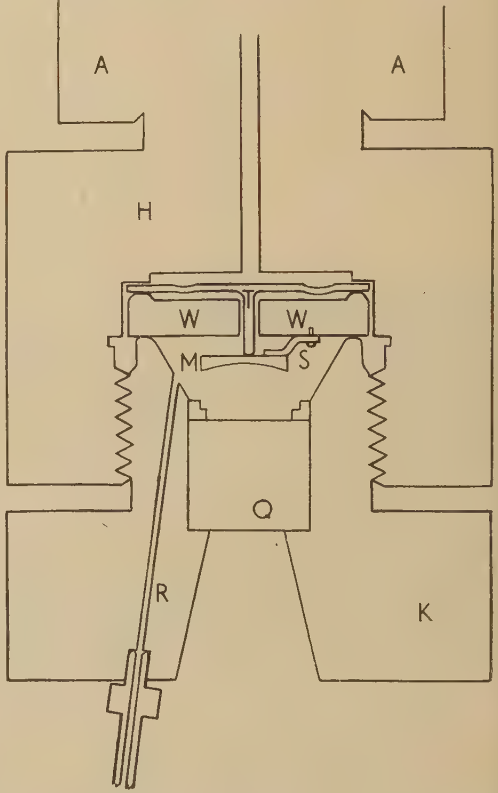
Finally, I wish to thank Professor J. D. McGee for interest and advice, and Messrs. J. French and G. Vick for their helpful assistance with the glass work.

A null-point pressure indicator for use at high temperatu

By P. E. Liley, B.Sc., Ph.D., A.Inst.P.,* Department Chemical Engineering and Applied Chemistry, Imperi College of Science and Technology, London, S.W.7

[*Note first received* 10 *December*, 1957, *and in final for* 1 *May*, 1958]

This device, which enables gas pressures up to 125 at temperatures up to 675° C to be transmitted with precision, is reproduced in the figure. A metal diaphra



Modified diaphragm device using cylindrical quar window

T is held in position in the plug *H* by means of the dista plate *W* and the screwed plug *K*. On one side it is in di communication with the contents of the vessel *A* (i.e.

---

* Houskeeper, W. G. *J. Amer. Inst. Elect. Engrs*, **42**, p. 954 (1923).

* Now at School of Mechanical Engineering, Purdue Univer Lafayette, Indiana, U.S.A.

›f which the pressure is desired), and on the other side compressed nitrogen (or suitable inert gas) which leads *R* to the pressure measuring and regulating equipment. nitrogen occupies a chamber in the plug *K*, one side hich is fitted with a quartz window *Q*. Any movement ie diaphragm resulting from an unbalanced pressure is ated by the movement of a beam of light reflected from odium plated nickel mirror *M* which is mounted on a ıg *S*. The mirror rests on a pin attached to the centre ie diaphragm.

ıe metal housing is of stainless steel, thread lubrication ; provided by the use of the proprietary "Ragosine anti- ing paste." For high sensitivity and thermal resistance diaphragm was constructed of 0·0035 in. pure nickel with a circular corrugation near its boundary. In work e 450° C, the thickness of the nickel sheet was increased ·0040 in. in order to provide the necessary thermal tance.

ıe window material is of quartz of length 1 in. and ıeter $\frac{3}{4}$ in. In ambient temperature work, a conical low with half-angle approximately 2° proved perfectly factory. This was ground into position in the block *K*. work at higher temperatures the relative quartz metal nsion precluded this arrangement and a cylindrical low was used. Leakage at the seating of the window the block *K* was obviated by using an annular copper of thickness 0·002 in.

ıe motion of the diaphragm due to unbalanced pressures luced by temperature variation is observed and the sure of the inert gas adjusted so as to maintain the hragm in the undeflected position. Accurate measure- t of the nitrogen pressure will then give the pressure in vessel *A*.

actual trials with the system, the sensitivity of the cted beam was above 1 mm displacement/mm of mercury sure differential at pressures up to 125 atm. It was found sable to replace each diaphragm after one heating at the er temperatures as pin-holes were found to occur in e cases when a diaphragm was subjected to two heating cooling cycles.

ıe author is indebted to the Admiralty, which sponsored work, for permission to publish this note. He would like to thank Prof. D. M. Newitt for his supervision of work which forms part of that undertaken for the ee of Doctor of Philosophy in the University of London.

general purpose electronic timer particularly suitable for time-lapse kinemicrography

y D. McNish, and R. E. Trotman, B.Sc., Grad.Inst.P.,
hysics Department, Westminster Hospital, London,
S.W.1

[*Note received* 23 *December*, 1957]

apparatus described by Cliffe(1) requires the 230 V a.c. ıs to operate a clutch mechanism at regular intervals of ı 1 to 45 s with an accuracy of 1%. This mechanism is uently used for other purposes and this note describes a ɔle timer which has been developed to operate it. The rument is also useful as a general purpose timer, having advantage of possessing a controlled and variable pulse th, by which is meant the length of time the timer contact osed, as well as the variable repetition time.

Iany timers have been described in the past,(2,3) but the ɔduction of a new close tolerance trigger tube(4) has roved the technique. The stimulator used by Leatham, Cook and Davies,(5) uses this tube, but the circuit was found to be unsatisfactory owing to poor extinguishing of the tube, uncertain relay operation at high speeds and its dependence on individual tube characteristics. In the circuit described below a simple device has been used to extinguish the tube and it gives complete freedom from these defects.

Fig. 1 shows the fundamental trigger tube circuit. A voltage, applied to the points X and Y, charges up C_1, through R_1, in a time depending on the time constant C_1R_1 which is variable. When the voltage across C_1 reaches the triggering voltage of the tube, the tube fires and its anode is maintained at a potential of approximately 100 V. The resulting current in the anode load brings on relay *A* which contains the timer contact.

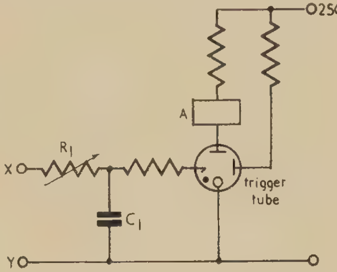


Fig. 1. The basic timing circuit

The relay will now remain on until the tube is extinguished and reverts to its non-conducting state. Self-extinguishing circuits(4,5) are frequently used today, but owing to the defects mentioned, this operation is performed a fixed time after relay *A* has closed by using another relay as shown in Fig. 2. This appears to be a retrograde step, but the additional component need only be very small and in any case is worth the advantages its introduction provides.

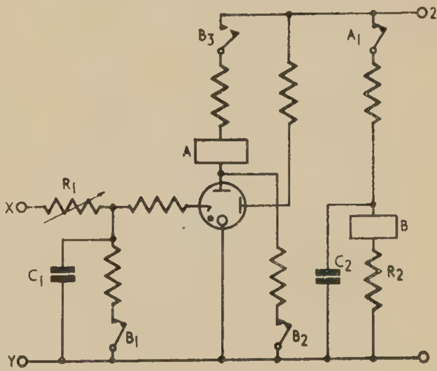


Fig. 2. The device used to control the pulse length and extinguish the tube

Before relay *A* is energized, contact A_1 is closed and relay *B* is energized. The contacts of *B* then permit C_1 to be charged up and the tube to operate as described. When the tube fires and *A* comes on, contact A_1 opens and *B* will be released at a given time afterwards, depending on the time constant C_2 $(R_2 + B)$ which is variable. This is because C_2 has to discharge through R_2 and *B* thus producing a controlled lag in the release of *B*. The contacts of *B* now, firstly, discharge C_1 to its initial condition and, secondly, extinguish the tube by connecting the anode and trigger electrodes to the cathode and removing the high tension from the anode. The relay contacts and time constants must be arranged so that C_1 is completely discharged before A is released and the process repeated.

Fig. 3 shows a timer in which the extra contact on relay A controls the external circuit. This is the actual circuit used for the Cliffe(1) apparatus, but other contacts may be added as required. The repetition times here are: 1, 2·5, 8, 15, 24 and 45 s, and the pulse length, not critical in this application, is approximately 100 ms. The final setting of the repetition frequency is made on the range most frequently used by RV_1 and on other ranges by adding low value resistances to R_1. Standard tolerance components are used except for R_1R_2 and C_1C_2 where high stability resistors and low loss capacitors are necessary.

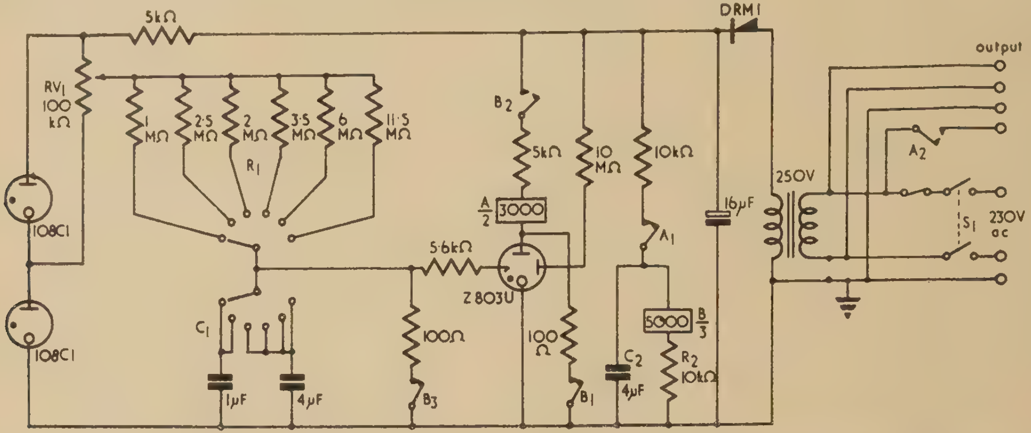


Fig. 3. The complete circuit diagram of the instrument as used for time-lapse kinemicrography

If it is desired to reset the timer manually instead of automatically, minor adjustments will make this possible. Re-initiating the timing period can also be made a separate operation. The instrument was made by one of us (D. McNish) and easily fits a case 6 × 10 × 7 in. and weighs 10 lb.

A simple electronic timer has been developed for time lapse photography which will probably be valuable in many other applications.

The time ranges are not limited to those used in this specific case. Repetition times of from 200 ms to 10 min are easily obtainable. It is possible to go up to 3 h,(4) but economics and the physical size of components limit this. Pulse len of 10 ms are feasible. The upper limit is again limited the physical size of components, but times up to 1 s reasonable.

The accuracy of the instrument is good. Long t variations of the tube stability, of the order of 1% car counteracted by RV_1. For short periods the accurac better than ±0·75%.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance of P R. J. V. Pulvertaft for whom the timer was developed Dr. C. W. Wilson, Chief Physicist at this hospital, in wh department the work was performed.

REFERENCES

(1) Cliffe, P. *Medical and Biological Illustration*, **2**, p. (1953).
(2) Deeter, E. L., and Dau, K. W. *Electronics*, **20**, p. (July, 1947).
(3) Frase, S. H. *Electronics*, **21**, p. 136 (April 1948).
(4) Gimson, K. F., and Growther, G. O. *Electronic En* **29**, p. 462 (1957).
(5) Leatham, A., Cook, P., and Davies, J. G. *Lancet*, p. 1 (1956).

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impr products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Hall effect generators. R. H. Cole (Overseas) Ltd., Caxton Street, London, S.W.1.

A range of devices is available, manufactured by Siemens and Halske, for the measurement of magnetic fields by means of the Hall effect. The instruments consist of an insulating base on which is deposited a layer of indium antimonide or arsenide furnished with current lead electrodes at either end and potential electrodes at the centre of each long edge. When a current is passed through the semi-conducting layer and a magnetic field is applied perpendicular to the plane of the layer, an e.m.f. is developed between the potential electrodes proportional to the product of the magnetic field and the energizing current. The device can therefore be used as a means of measuring a magnetic field or as a compu element (multiplier).

There are a range of sizes; the overall length (in direction of the exciting current) of the semi-condu varies from 4 to 16 mm, the width (in the direction of Hall e.m.f.) from 1·5 to 8 mm and the thickness (in direction of the magnetic field) from 0·05 to 0·1 mm. *overall* thickness in the last direction varies from 1 to 4 but for applications where it is necessary to make the in the magnetic circuit as small as possible the insula base of the device can be made of a ferrite material so a form part of the magnetic circuit; the gap is then simply 0·05 to 0·1 mm thickness of the indium antimonide

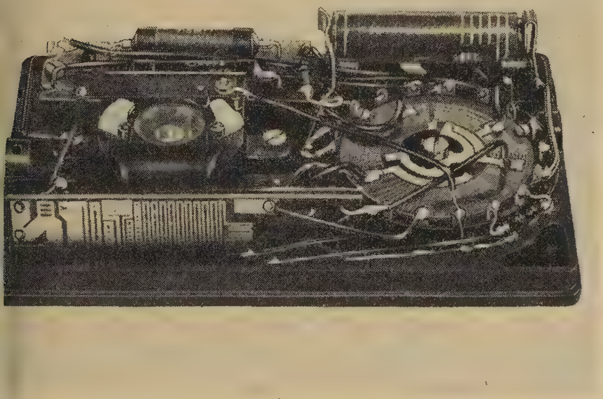
ide layer. The e.m.f. generated is of the order of V/A-kgauss and the maximum permissible energizing ent is, depending on the type of device, between 75 and mA.

c/s alternators. Laurence, Scott and Electromotors Ltd., Gothic Works, Norwich.

wide range of 400 c/s salient pole alternators is to have exceptionally good wave-form; the total nonic content of the output from a typical machine is d to be about 0·6%. Alternators are available which ate at speeds from 1200 to 3428 rev/min and with single hree-phase outputs from 1 to 200 kVA. The alternators supplied either for driving by a prime mover or as two-ing motor-alternator sets.

iature multi-range meter. Avo Ltd., Avocet House, 92–96 Vauxhall Bridge Road, London, S.W.1.

Multiminor model 2 meter has been designed as a small, pensive meter for use under adverse climatic conditions. components which can be moulded are made with a lding powder which gives high electrical insulation under litions of high humidity and resists the growth of fungus. movement is enclosed in a dust-proof casing, and all ng is termite proof. The selector switch consists of teen fixed silver-plated contacts rigidly held in a moulded and wiped by a double contact rotor arm. The instrut employs printed resistors made from a special metal y. The figure shows how a printed resistor has been bined with an auxiliary switch plate as an integral part he selector switch mechanism. High stability carbon stors are employed where necessary. The instrument has teen ranges. There are seven d.c. voltage ranges from mV to 1 kV and having a resistance of 10 000 Ω/V; a.c. voltage ranges from 10 V to 1 kV, with a resistance 000 Ω/V; five d.c. current ranges from 100 μA to 1 A; two resistance ranges of 20 kΩ and 2 MΩ. An accuracy to 4% of full scale is claimed.



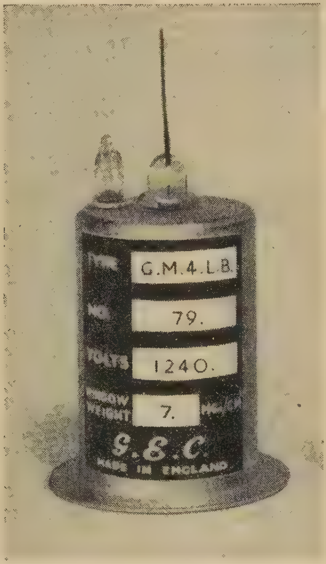
terior of multi-range meter showing printed resistors

h-sensitivity 5 in. cathode-ray tube. General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

5BHP tube has a 5 in. diameter flat face and employs a cal post-deflexion accelerator system in order to combine deflexion sensitivity with low distortion. A conventional t-deflexion accelerator consists of a conducting band applied to the inside of the tube near the screen to which a voltage of up to double that of the electron gun may be applied. Such a tube operating with a post-deflexion accelerating voltage (p.d.a.) of 10 kV would therefore have a gun voltage of 5 kV. If the ratio of the p.d.a. to the gun voltage is increased beyond 2, distortion of the trace occurs due to the action of the electrostatic lens formed between the p.d.a. band and the rest of the tube. The 5BHP tube, however, employs a resistive band in the form of a helix across which the accelerating potential is applied. The post-deflexion acceleration is therefore distributed along the whole length of the helix, which extends almost the whole distance from the deflector plates to the screen. The distortion is very much reduced by this means, so that it is possible for the ratio of p.d.a. to gun voltage to be increased to 6. With an accelerating voltage of 10 kV, the gun need then operate at only 1·67 kV. Since the deflexion sensitivity is inversely proportional to the gun voltage, a larger sensitivity is obtained and the 5BHP tube is stated to have a sensitivity of 1·5 mm/V. An additional refinement in this tube is provision for the adjustment of potentials on auxiliary electrodes when extreme precision of deflexion linearity and raster shape is required.

Geiger counter tube. General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

The type GM4LB Geiger tube has been designed to have an extremely low rate of count in the absence of the test specimen, and therefore to serve for the measurement of very minute amounts of radioactivity. It has a thin Duralumin window 1 in. diameter and of weight 7 mg/cm². The length of the anode wire has been kept to a minimum to reduce the response to any extraneous radiation and the materials used in the construction have been specially selected as free from radioactive contaminants, such as potassium and lead, which might contribute to the background count. In order to obtain the minimum background response, the tube must be operated in a heavily shielded enclosure and surrounded by a ring of γ-ray counters connected in an anti-coincidence network. This ensures that external radiation passing through the counter ring is not recorded by the measurement tube. Background responses as low as 0·4 counts/min have been obtained in this way, thus enabling specimens with an extremely low activity to be measured.



Geiger tube with low background count

Electrolytic polisher. Shandon Scientific Company Ltd., 6 Cromwell Place, London, S.W.7.

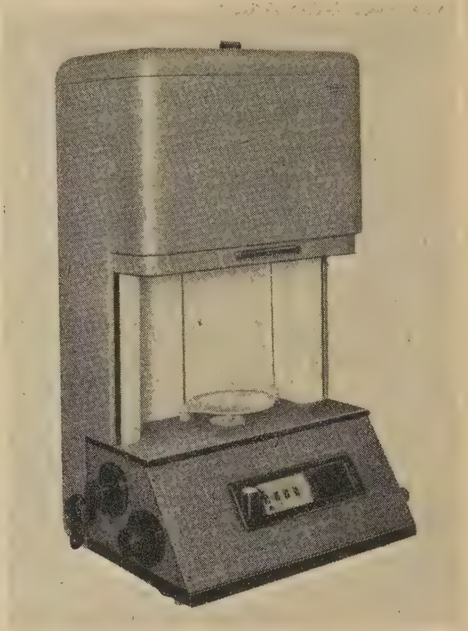
An electrolytic polisher is now available based on the designs of Sykes, Haddrell, Haines and Mott.* The principle of the operation of the instrument is that the electrolyte is driven by a centrifugal pump through a series of holes so that it impinges on the specimen as a rotating, continuously renewed liquid column. This ensures a uniform polish and finish without flow lines. The polishing deck, which contains the pump with its motor, the specimen clamp and the electrolytic cell forms a self-contained unit mounted on P.V.C. and resting on the electrolyte tank. The pump is made from P.V.C. and polythene and all components in contact with the electrolyte are made from corrosion resistant material. The power supply has separate d.c. outputs and controls for manual and automatic polishing and etching. Additional output terminals provide facilities for beaker etching when required. With manual control, all operations are controlled by on/off switches. With automatic operation, the time switch is set to the required polishing period (within a range of 1–90 s). At the end of the period both the pump and the current are automatically switched off. Electrolytic etching can be carried out as part of the operation by switching to "etch" during the last seconds of the cycle.

Electrolytic polishing and etching equipment

* Sykes, Haddrell, Haines and Mott. *J. Inst. Metals*, **83**, p. 166 (1954).

Single pan balance. Stanton Instruments Ltd., 119 Oxford Street, London.

A single pan balance known as the Ultramatic has the counter-indicator of the loads applied, adjacent to the graticule screen. Two basically similar models are made with sensitivities of 1 mg and 0·1 mg respectively. The 5 in. beam is of hard brass and has agate knife edges on synthetic sapphire planes. Stainless steel is used for the pan and pan wires which are 4 in. apart and give a weighing height of 7 in. Two knobs, each giving partial and full release, are located one at each side of the cabinet for ease of handling. Four weight loading dials, arranged in two concentric banks on the left-hand side of the balance, give external wei loading up to 200 g without the use of loose weights or ex dials. All weights applied are shown on the counter mech ism located on the base plate at the front of the bala adjacent to the graticule screen. The latter is graduat 500 divisions each equivalent to 2 mg or 0·2 mg depe on the model. Synchro-release, which can be fitted as optional extra, automatically operates and controls release of the beam independent of the skill of the opera



Ultramatic single pan balance

British Journal of Applied Physics

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ORIGINAL CONTRIBUTIONS

A calculator for numerical Fourier synthesis*

By V. Timbrell, Ph.D., D.I.C., A.R.C.S., B.Sc., Pneumoconiosis Research Unit, Llandough Hospital, Penarth, Glamorgan

[*Paper first received* 11 *December*, 1957, *and in final form* 5 *May*, 1958]

The customary numerical method of Fourier synthesis, using three figure tables, is accurate but laborious and slow. The calculator described makes the method ten times faster, and the accuracy is about the same. It is especially useful for the occasional synthesis which does not justify an automatic machine.

For each of twelve harmonics, expressed in the form $R_k \sin(\phi_k + k\theta)$, numerical values are obtained for $\theta = 0°, 7\frac{1}{2}°, 15°, \ldots 352\frac{1}{2}°$. These are recorded on a work-sheet and the sum $\sum_{k=1}^{k=12} R_k \sin(\phi_k + k\theta)$ is got by simple addition for each value of θ. Full use is made of the frequent recurrence of values for some harmonics in order to minimize the number of readings that must be taken from the calculator. The principle is applicable to any values of k and any of the commonly used intervals of θ.

A mechanical Fourier synthesizer of simple construction for handling fifteen harmonics is described in an appendix. This instrument enables the synthesized waveform to be plotted directly.

METHOD

e Fourier series is expressed in the form

$$\sin(\phi_1 + \theta) + R_2 \sin(\phi_2 + 2\theta) + \ldots$$
$$R_k \sin(\phi_\kappa + k\theta)\, k\theta + \ldots R_{12} \sin(\phi_{12} + 12\theta)$$

information given being the values of the amplitudes R_2, R_3 . . . and the phase angles ϕ_1, ϕ_2, ϕ_3 . . . of the monics. The sum of the series is required for each of 48 ues of θ, namely, 0°, 7½°, 15°, . . . 352½°. The complete nputation is contained in the table on p. 314.

The calculator is used to find the numerical values of the ms by *columns*, i.e. for each value of k in turn. These recorded in the lower table of the previously prepared rk-sheet shown in Fig. 1. The sums S_0, S_1, S_2, S_3 . . . are n obtained by simple addition, preferably on an adding ichine. There may be a constant term R_0 in the series d a column is provided for it. The upper table of the workeet is a record of the given information.

To minimize the number of values that must be found m the calculator use is made of the fact that since $\alpha = -\sin(\alpha + 180°) = \sin(\alpha + 360°)$ the values in a lumn recur repeatedly in some columns. For instance, if the ree basic values for $k = 8$ and $\theta = 0°$, 7½° and 15° are und, they can be repeated to fill the column, as illustrated Fig. 1. In any column, the thick broken lines show iere the values must be repeated with the signs changed, d the thick continuous lines show where the values must repeated with the signs unchanged.

(In the customary numerical method, each harmonic $\sin(\phi_k + k\theta)$ is expressed as $a_k \cos k\theta + b_k \sin k\theta$, where $= R_k \sin \phi_k$ and $b_k = R_k \cos \phi_k$. For each value of θ, s $k\theta$ and $\sin k\theta$ are found from tables [1] and are multiplied a_k and b_k respectively; the sum of the values of all the rmonics is then obtained.

Compared with this method, the modification described re reduces the number of values that must be found to 1, eliminates the laborious multiplications, reduces the tal number of terms involved to a quarter, and makes iecking of the work much easier.)

THE CALCULATOR

The calculator is based on the familiar geometrical model used to illustrate simple harmonic motion. The amplitude R_k of a harmonic is represented by the length of a radius vector which can be rotated about one end. The radius vector is rotated to make with a horizontal line the angles ϕ_k, $(\phi_k + k.7\frac{1}{2}°)$, $(\phi_k + k.15°)$ . . . ; the projections of the radius vector on a vertical line represent the values of the harmonic for $\theta = 0°$, 7½°, 15° . . . and the numerical values are read from a scale.

The calculator shown assembled in Fig. 2 consists of a fixed scale, Fig. 3, and three engraved Perspex disks—disk *A* Fig. 4, disk *B* Fig. 5, and a disk *C* which is one of a set. Disk 1*C*, shown in Fig. 6, has radial markers in the spiral at intervals of 1 × 7½°; disk 11*C*, shown in Fig. 7, has radial markers at intervals of 11 × 7½°, and so on. The markers on each disk *C* are numbered consecutively, but the numbers have been omitted as they would not reproduce clearly and the markers are indicated instead by M_0, M_1, M_2, M_3 . . .

Suppose that the values of the 11th harmonic with $R_{11} = 628$ and $\phi_{11} = 55°$ are to be found. To do this the calculator contains the disk 11*C*, as shown in Fig. 2, and is operated as follows:

(1) The pin is pushed into the stub and the screw loosened so that the disks can rotate independently of one another.

(2) The disk *A* is rotated to set 90° on the protractor to the datum line *d*. The radius vector is then vertical.

(3) The disk *B* is rotated so that P, the point of intersection of the spiral and the radius vector, reads 628 on the scale.

(4) The disk 11*C* is rotated to set the 0 marker, M_0, to 55° on the protractor.

(5) The screw is tightened to clamp the three disks together between the washer and the stub, and the pin is withdrawn. The combination of disks is now free to rotate.

(6) The combination is rotated to set the markers 0, 1, 2, 3 . . . 23 to the datum line in turn. The scale readings of the point *P* give the values for $\theta = 0°$, 7½°, 15° . . . In Fig. 2 the calculator is set for $\theta = 22\frac{1}{2}°$, the value of the

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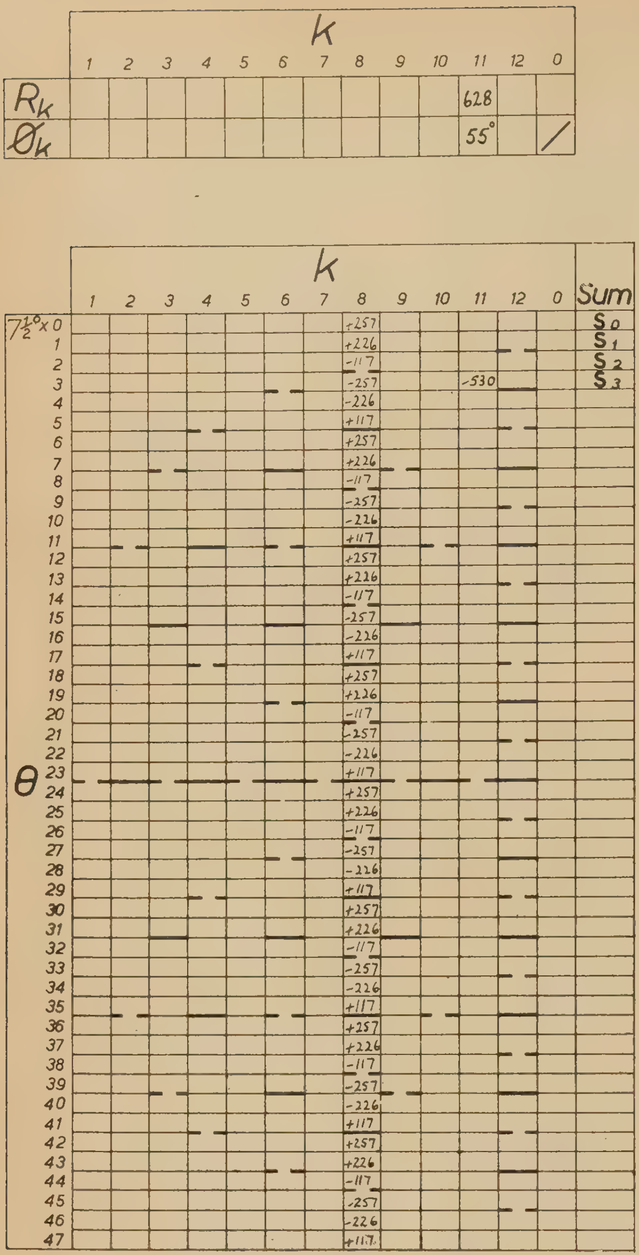
* The calculator will shortly be manufactured by W. F. Stanley d Co. Ltd., New Eltham, London, S.E.9.



	k												
	1	2	3	4	5	6	7	8	9	10	11	12	0
R_k											628		
$\emptyset_k$											55°		/

θ	1	2	3	4	5	6	7	8	9	10	11	12	0	Sum
7½°× 0								+257						S_0
1								+226						S_1
2								−117						S_2
3								−257			−530			S_3
4								−226						
5								+117						
6								+257						
7								+226						
8								−117						
9								−257						
10								−226						
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16								−226						
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44								−117						
45								−257						
46								−226						
47								+117						

Fig. 1. The work-sheet

term being −530. When the values have been inserted the column for $k = 11$ and the thick line reached, the val are repeated to fill the column.

For any of the other harmonics the rate of change of angle $(\phi_k + k\theta)$ with θ depends on k, and a different disk with markers at the appropriate intervals must be used. separate disk C, carrying markers 0 to 47, can be provi for each harmonic, but this is necessary only if the sum the series is required for one particular value of θ, and the results are to be obtained directly without using recurrence of terms.

Usually the sums of the series for all values of θ required and the recurrence of terms can be used. For th complete syntheses, it is possible to economize in mate and time by using certain of the disks C for more than harmonic. For example, the disk 1C used for the 1st h monic can also be used for the 2nd harmonic, by setting calculator initially to R_2 and ϕ_2 in the usual way, and t setting the markers 0, 2, 4, 6, 8 . . . 22 to the datum line turn. Similarly, the disk 1C can be used to find the ba values of the 3rd, 4th, 6th, 8th and 12th harmonics, set to every 3rd, 4th, 6th, 8th and 12th markers respectiv always starting from 0. For these harmonics the ba values are few, and it is easy for the operator to work mentally the actual numbers of the markers to use. markers 0 to 23 are necessary on the disk 1C. It is convenient to use the disk 1C for the remainder of 12 harmonics—the 5th, 7th, 9th, 10th and 11th—bec many additional markers would be needed on the disk; a the operator would probably make mistakes in working which markers to use, and the search for markers would ta too long. Disks 5C, 7C, 9C and 11C, each carrying mark 0 to 23, are therefore provided for the 5th, 7th, 9th a 11th harmonics respectively. The 12 basic values of 10th harmonic can be found by using disk 5C, and sett to the markers 0, 2 . . . 22.

The calculator handles three digit numbers. Four sca are provided:

200 to −200 on $\frac{1}{5}$ in. graph paper
400 to −400 on $\frac{1}{10}$ in. graph paper
800 to −800 on $\frac{1}{20}$ in. graph paper
1000 to −1000 on 1 mm graph paper

Each scale is made by pasting a circle (8 in. diam.) of gra paper between a square sheet of thin Perspex, 14 × 14 and a similar square of drawing paper, so that the prin side of the graph paper is seen through the Perspex; o one of the two printed sets of grid lines is used. Holes

Table. *Complete Fourier series*

	k 1 . . .	8 . . .	11 . . .	Su
$\theta = 7\frac{1}{2}° \times 0$	$R_1 \sin(\phi_1 + 0) + \ldots$	$R_8 \sin(\phi_8 + 0) + \ldots$	$R_{11} \sin(\phi_{11} + 0) + \ldots$	S_0
1	$R_1 \sin(\phi_1 + 7\frac{1}{2}°) + \ldots$	$R_8 \sin(\phi_8 + 8.7\frac{1}{2}°) + \ldots$	$R_{11} \sin(\phi_{11} + 11.7\frac{1}{2}°) + \ldots$	S_1
2	$R_1 \sin(\phi_1 + 2.7\frac{1}{2}°) + \ldots$	$R_8 \sin(\phi_8 + 2.8.7\frac{1}{2}°) + \ldots$	$R_{11} \sin(\phi_{11} + 2.11.7\frac{1}{2}°) + \ldots$	S_2
3	$R_1 \sin(\phi_1 + 3.7\frac{1}{2}°) + \ldots$	$R_8 \sin(\phi_8 + 3.8.7\frac{1}{2}°) + \ldots$	$R_{11} \sin(\phi_{11} + 3.11.7\frac{1}{2}°) + \ldots$	S_3
.				
.				
.				
.				
.				
47	$R_1 \sin(\phi_1 + 47.7\frac{1}{2}°) + \ldots$	$R_8 \sin(\phi_8 + 47.8.7\frac{1}{2}°) + \ldots$	$R_{11} \sin(\phi_{11} + 47.11.7\frac{1}{2}°) + \ldots$	S_4
.				

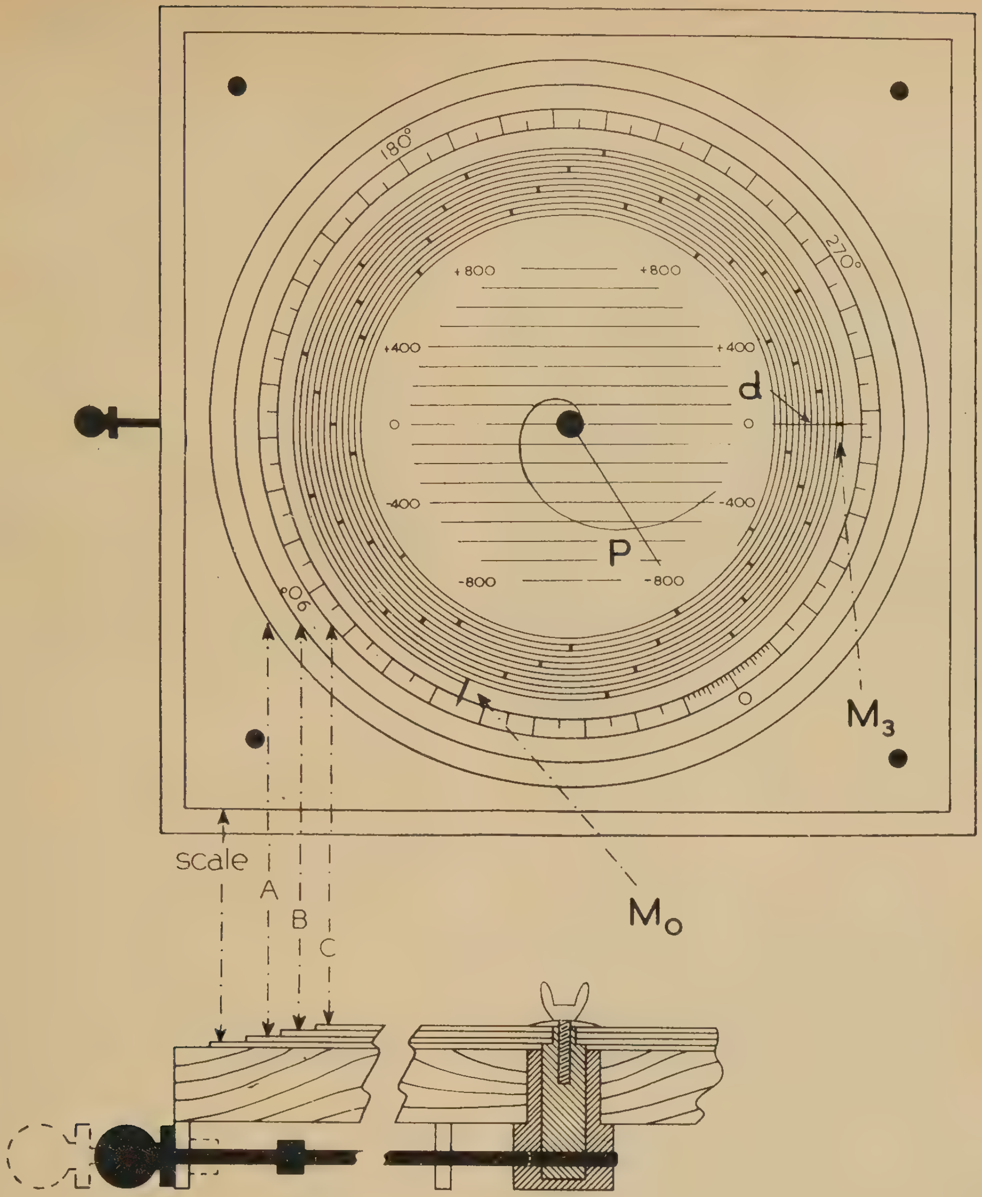

Fig. 2. The calculator assembled to find the values of the 11th harmonic, and set for $\theta = 22\frac{1}{2}°$. (Not to scale)

corners of a scale enable it to fit on the pegs in the base ard.

The scale used for a given Fourier series is determined by greatest amplitude present. For instance, if the greatest plitude is 3·71, all the amplitudes are multiplied by 100, d the 400 to −400 scale is used. The same scale is used all the harmonics since there is no point in changing it obtain greater accuracy in the values of some harmonics n of others. If, however, an amplitude is so small that radius vector would be covered by the washer clamping disks, the amplitude is multiplied again by 10 and the ues divided by 10 as they are found. The sums are divided 100.

The disk *A* is 13 in. in diameter. The disk *B* is 12½ in. diameter. The spiral on this disk is equiangular so that intersection with the radius vector is always the same d nearly a right angle. To construct the spiral 21 radii drawn on paper at intervals of 18°; the first radius is 4 in. and the logarithms of the lengths of the other radii decrease in steps of 0·05. A smooth curve is drawn through the extremities of the radii and is then traced on to the disk.

The disks *C* are 12 in. in diameter. The spirals on them have ⅛ in. pitch and are engraved by means of a lathe. A dividing head is used to engrave the markers. If each disk *C* carries only the essential 24 markers the diameters of the scales can be increased.

The central holes in the scales are ½ in. in diameter and those in the disks ¼ in. in diameter.

DISCUSSION

A calculator can be designed for any number of harmonics and for any of the commonly used intervals of θ, such as 3°, 6°, 3¾°. It should be designed for the smallest interval likely to be required as it can then also be used for multiples of this interval.

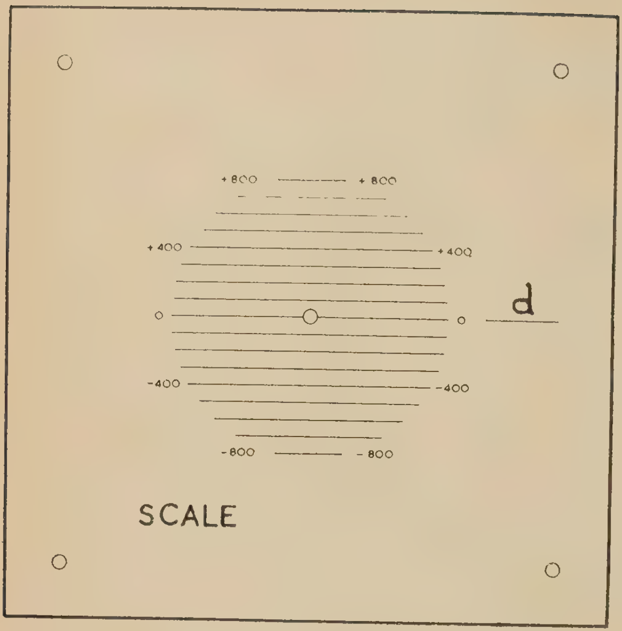
+800
+800
+400
+400
0
0
-400
-400
-800
-800
d
SCALE

Fig. 3. A typical scale

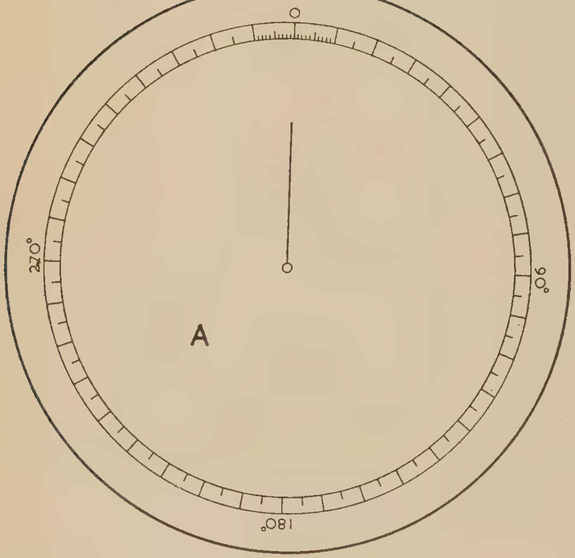
0
90°
180°
270°
A

Fig. 4. Disk *A*

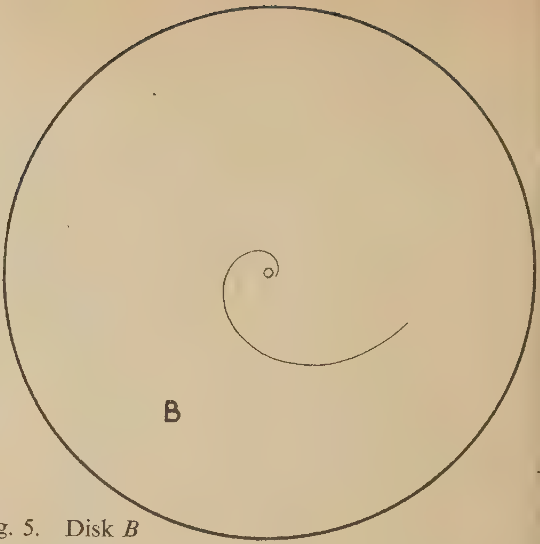

Fig. 5. Disk *B*

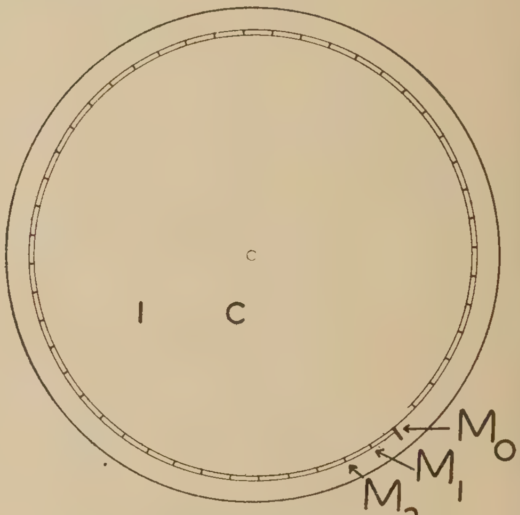

Fig. 6. Disk 1*C*

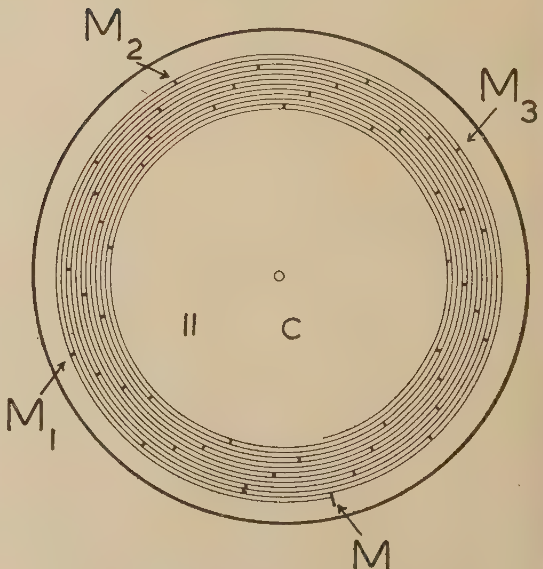
M_2
M_3
II C
M_1
M_0

Fig. 7. Disk 11*C*

is easy to work out what disks C are necessary, and what kers are required on each to enable all the basic values ll the harmonics to be found.

REFERENCES

Manley, R. G. *Waveform Analysis* (London: Chapman and Hall Ltd., 1945).

Thomson, W. *Proc. Inst. Civil Engrs*, **65**, p. 15 (1881).

APPENDIX

A mechanical Fourier synthesizer of simple construction

ike similar machines described in previous literature the described here generates the harmonics, expressed in the n $R_k \sin(\phi_k + k\theta)$, as displacements, at speeds propor-ial to the orders, k's, of the harmonics. The displacements added together by means of a Kelvin adding mechanism.(2) number of points on the synthesized waveform can plotted on graph paper. The method of generating the placements is such that the machine, which can handle harmonics, is compact and simple to construct from ccano and easily-made parts.

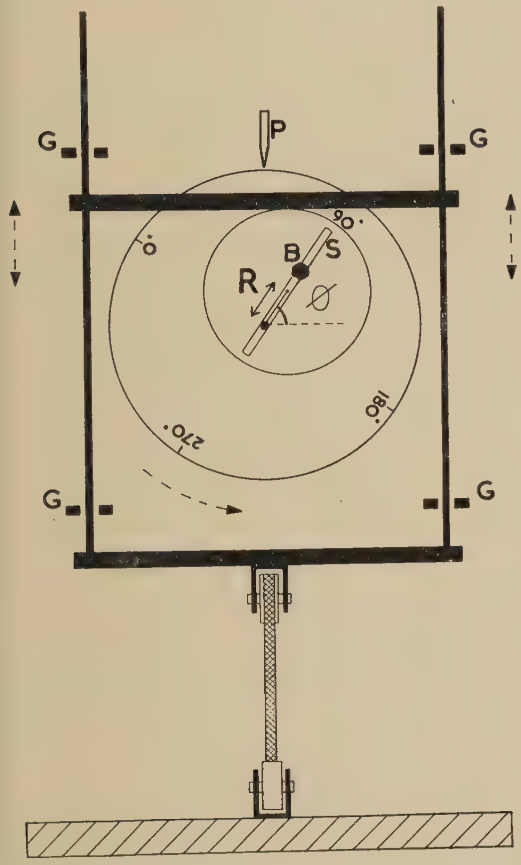

Fig. 8. Diagram of the front of a generating unit

Fig. 8 shows diagrammatically the front of a generating it; there is one such unit for each harmonic. Fig. 9 shows back of the unit for the 15th harmonic. In each unit, a all disk which has a diametrical slot S is held against the front surface of a large disk by means of a bolt B screwed into the large disk. The large disk carries on its back surface a standard protractor, and can rotate about a fixed horizontal shaft through its centre; the protractor can be set against the pointer P. A rigid rectangular frame hangs with the upper cross-head resting on the wide rim of the small disk ($\frac{3}{8}$ in. thick). The guides G allow only vertical motion of the frame. The crossheads never reach the shaft, and this feature enables the units to be mounted one behind the other, as shown in Fig. 10, with all the large disks on the same fixed shaft, making the construction simple.

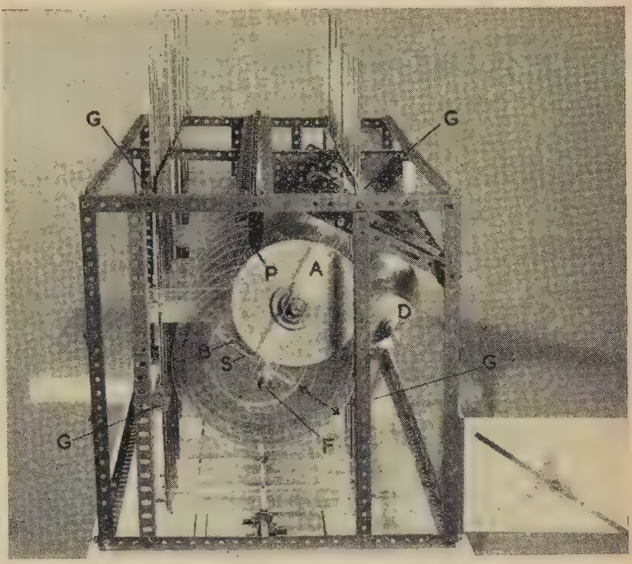

Fig. 9. Back view of the machine, showing the back of the unit for the 15th harmonic; the supports for the shafts have been removed

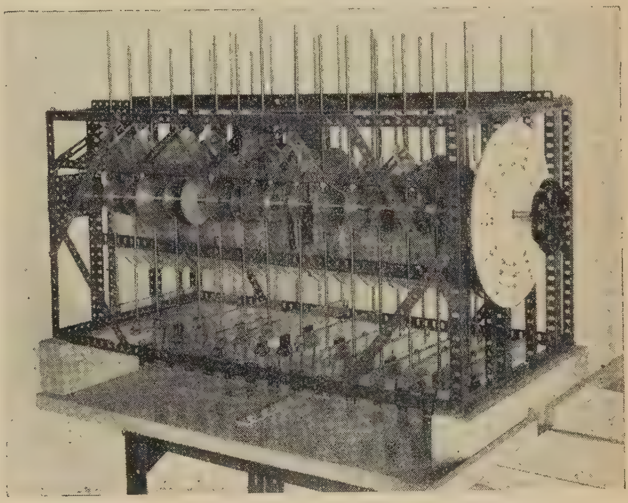

Fig. 10. Side view of the machine; some of the driver and idler gear wheels have been put out of mesh for clarity

Each unit has a gear train of three wheels (Government surplus), as shown in Fig. 9. One wheel is on the driving shaft D and can be secured to it by means of a grub screw. The second, "idler," wheel is on a stub-axle carried by the arm *A* which has the fixed shaft *F* passing through a hole at one end; the other end of the arm is connected to the chassis by a strut. The third wheel is secured to the back surface of the large disk. The table shows the number of teeth on the wheels. The gear train in the unit for the 1st harmonic has a step down ratio of 4 : 1.

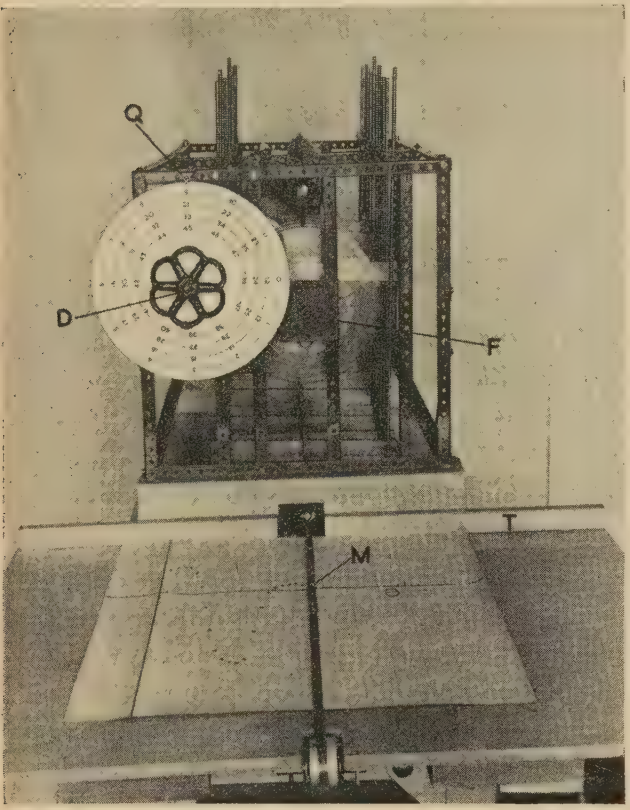

Fig. 11. Front view of the machine

The dial on the driving shaft is graduated from 0 to 47 (see Fig. 11) with a 30° spacing; the dial can be set against the pointer *Q*. Rotation of the dial from one scale mark to the next corresponds to a $7\frac{1}{2}°$ change in θ.

The tape of the adding mechanism runs over all the pulleys carried by the frames and those fixed to the base of the machine (see Fig. 10). In order that the lengths of tape between the pulleys may be vertical each pulley has a diameter ($\frac{3}{4}$ in.) equal to half the length of the machine occupied by each unit ($1\frac{1}{2}$ in.); an extra pulley on the base compensates for the length of the machine occupied by the supports for the shafts between the 7th and 8th units. The end of the tape at the back of the machine is fixed, while the other end is pulled taut across the graph paper by a hanging weight.

The units are set to the amplitudes and phase angles follow:

(1) The grub screws in the driver wheels are loose The driving shaft is now free and is rotated to set the dial t

(2) In each unit, the bolt clamping the two disks is loosen The small disk is moved along the 90° radius of the p tractor, the bolt and fixed shaft, which fit neatly in the s acting as guides, so that the distance between the centres the disks equals the length representing the amplitude of harmonic. A convenient way of doing this is to make distance between the rims of the disks along the 270° rad of the protractor (shown dotted in Fig. 9) equal to required length plus the difference ($1\frac{1}{2}$ in.) between the ra of the disks ($3\frac{1}{4}$ in. and $1\frac{3}{4}$ in.); a depth gauge (shown in in Fig. 9) fitted with an extension piece is used, the scale the gauge being set to the length. The bolt is then tighten

(3) In each unit the protractor is set to the proper ph angle.

(4) The grub screws in the driver wheels are tightened.

Graph paper scaled in centimetres or inches is us depending on the scale chosen for the amplitudes. spacing of the scale on the ordinate axis must be twice t of the scale used for the amplitudes, since the second-or pulley system doubles the displacements.

With the dial set at 0 and the graph paper against guide bar *T*, an index mark *M* is made on the tape wher crosses the axis of θ, but should there be a constant co ponent R_0 in the Fourier series the index mark is made the tape where it crosses a line of ordinate R_0.

The dial is set to the scale marks in turn, the weight the tape being lifted when the machine is in motion minimize stresses. At each setting the ordinate of the po on the waveform is the ordinate of the index mark; it convenient to move the graph paper along its guide so t the point to be plotted is always close to one edge of the ta

Rotation of the driving shaft is assisted by the mome about the fixed shaft of some of the frames and eccentrica placed small disks, and almost equally opposed by moments of the others, and therefore requires little effo It helps if the crossheads and small disks are made of so light material such as Perspex, if ball-races are used for pulleys and for the bearings of the shafts, and if the tape made from photographic film, which springs away from the pulleys when the weight is lifted. All gear ratios between 4 : 1 and 1 : 4, resulting in satisfactory mechani advantages and wheel sizes.

There is some latitude in the sizes of the idler gear whe but gear wheels near the minimum possible sizes are avoid as they cause the two shafts to be forced apart when machine is working.

If care is taken in constructing the machine and it operated always in the same direction to avoid backlash, position of the index mark is repeatable to ± $\frac{1}{8}$ in. T displacement of the index mark could be 6 ft., giving possible error of ± 0·2%, but it is usually about 15 i giving a possible error of ± 1%.

Complete Fourier series

k	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. of teeth on 1st (driver) gear wheel	48	48	72	96	120	72	84	96	108	120	88	144	78	84
No. of teeth on 2nd (idler) gear wheel	72	168	150	124	120	192	192	180	156	150	192	125	216	208
No. of teeth on 3rd (driven) gear wheel	192	96	96	96	96	48	48	48	48	48	32	48	24	24

A microwave spectrometer for the study of free radicals

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[*Paper received* 20 *February*, 1958]

A microwave spectrometer suitable for the study of short-lived molecules in the gas phase, in particular free radicals, has been constructed to operate over a frequency range from about 20 to 70 kMc/s. An innovation is the use of surface wave propagation of the microwaves along a wire in the absorption cell, a system which has very wide band-pass properties. High sensitivity is obtained by using a radio-frequency modulation of the klystron source. The apparatus is described in detail, with some account of the underlying principles, and preliminary results with the short-lived substance carbon monosulphide are presented.

ite the large volume of material published in recent years ıe microwave spectroscopy of gases, very little of it is erned with the study of short-lived molecules, such as r as important intermediates in various chemical ions. Some measurements have been made on the radical[(1)] and the carbon monosulphide molecule[(2)] ; fairly conventional instruments, and a spectrometer ble for free radical work, using an absorption cell with owave lenses, has been described by Costain.[(3)] The on for this apparent neglect lies in the inherent experi- al difficulties, which are principally:

the production of the radicals in sufficient quantity to iit microwave measurements—pressures of at least mm of mercury are required, with total pressures of the order;

) the loss of sensitivity necessarily encountered in dealing substances of short life. The high sensitivity of most ern microwave spectrometers depends on the use of very sweeps of the frequency of the microwave source across rption lines, in conjunction with very narrow band-pass lifiers, thus giving high signal/noise ratio. This slow p (1 c/s or less) must be sacrificed for substances of mean of the order of milliseconds;

i) the production of suitable absorption cells, with as metallic surface as possible, so as to limit the recom- tion of free radicals in wall reactions.

he authors have regarded as potential methods for pro- ion of free radicals both the method of flash photolysis, loped by Norrish, Porter and their co-workers in this ratory,[(4)] and radio-frequency discharge. The apparatus h has been constructed is suitable for the application of r of these techniques. The second difficulty has been imized by use of an r.f. source-modulation technique.[(5)] enables a silicon crystal to detect the microwave power ıe radio-frequency, and thus avoids the excessive noise rated in crystals at lower frequencies which will lie out- the band-pass of the recording system. The third culty has been resolved by use of a cell with surface propagation along a central wire in a quartz or glass lope, in which the ratio of metallic surface to total ace is extremely small.

the work on OH reported above,[(1)] the method of nan modulation, rather than source modulation, was . This is readily possible with free radicals because of high magnetic moments, arising from the odd electron. as been rejected here as a means of modulation for a ber of reasons: the field distribution of the microwaves he wire in the absorption cell is such that application of eman field would give a large number of component lines, eby reducing the individual intensities, possibly to too a level for detection; the high frequencies of modulation h are catered for in this instrument are much more suitable for application as source (klystron) rather than Zeeman modulation. Provision has been made for application of a d.c. magnetic field of the order of 100 G from an external solenoid, which will be valuable in showing whether an observed line is due to free radicals.

THE ABSORPTION CELL

Fig. 1 shows a diagram of one of the ends of the absorption cell, the total length of the cell being 3 m. Fig. 1(*a*) shows the mode of construction and assembly and (*b*) shows the assembled system. Microwave radiation from a rectangular waveguide (operating in the TE_{10} mode) is launched on to a short length of coaxial line, the outer conductor of which, after passing a vacuum seal, is flared into a cone. This gives a surface wave with a field confined to a short distance from the central wire conductor. A similar system transforms back to a rectangular waveguide at the other end of the cell. The theory of such propagation has been discussed in detail by Gobau.[(6)] Briefly, the condition for propagation of a surface wave is that the phase velocity of the wave along the guiding structure must be less than that of a TEM wave in an unbounded similar medium. The fulfilment of this condition is ensured by the non-zero resistance of the wire.

The field pattern of the surface wave is shown in Fig. 2(*a*), and is seen to be very similar to that of the inner conductor for the TM_{01} mode [Fig. 2(*b*)] of a coaxial line. Thus, in the first place, the coaxial line was made big enough to transmit this mode, which should be readily excited from the waveguide source. No transmission was obtained. If, however, the coaxial line was made so small as only to be able to propagate the fundamental TEM mode, good transmission occurred. In the former case, it is probable that the TE_{11} mode is excited in the line; this is the first mode above the TEM one, and has a field [Fig. 2(*c*)] quite unsuitable for launching on to a single wire.

These transformer sections showed a sharp high-frequency cut-off, occurring as soon as the coaxial line was able to transmit the TE_{11} mode. In the final model, the radii of the inner and outer conductors of the coaxial section were 0·23 and 0·80 mm respectively, giving high-frequency cut-off at about 4 mm (75 kMc/s). The low-frequency cut-off was determined only by losses from interference with the walls of the cell. At low frequencies the field extends further from the wire. The eventual choice of cell was a Pyrex tube 3 m long, and 35 mm in diameter, which was satisfactory up to wavelengths of 15 mm (20 kMc/s). A quartz tube would be necessary for some flash photolytic purposes. The total attenuation introduced by two transformers of the type shown in Fig. 1 was in the region of 8–10 dB over this range of wavelengths (4–15 mm). Overall losses of the cell, including the ends, using copper wire of 0·018 in. diameter, were

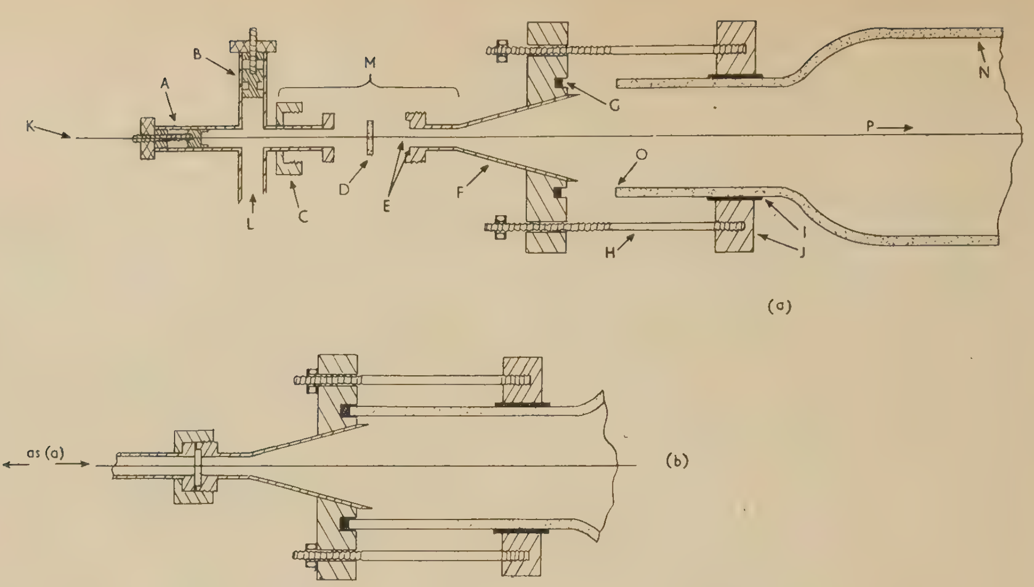


Fig. 1. Transformer section to absorption cell: (*a*) prior to assembly; (*b*) assembled

A, coaxial bucket-type shorting plunger; *B*, waveguide shorting plunger; *C*, threaded ring collar; *D*, Alkathene disk vacuu seal, 0·5 mm thick; *E*, surface painted with glyptal sealing compound; *F*, electro-plated cones for launching surface wave; ring groove with neoprene vacuum rings; *H*, four brass 6 B.A. tie bars; *I*, rubber sleeve to secure split-ring clamp *J*; 0·018 in. diameter copper wire terminating in rigid support; *L*, microwave power input in waveguide; *M*, coaxial sectio ; *N*, 3 m Pyrex tube terminated in identical transformer; *O*, ground glass end; *P*, surface wave.

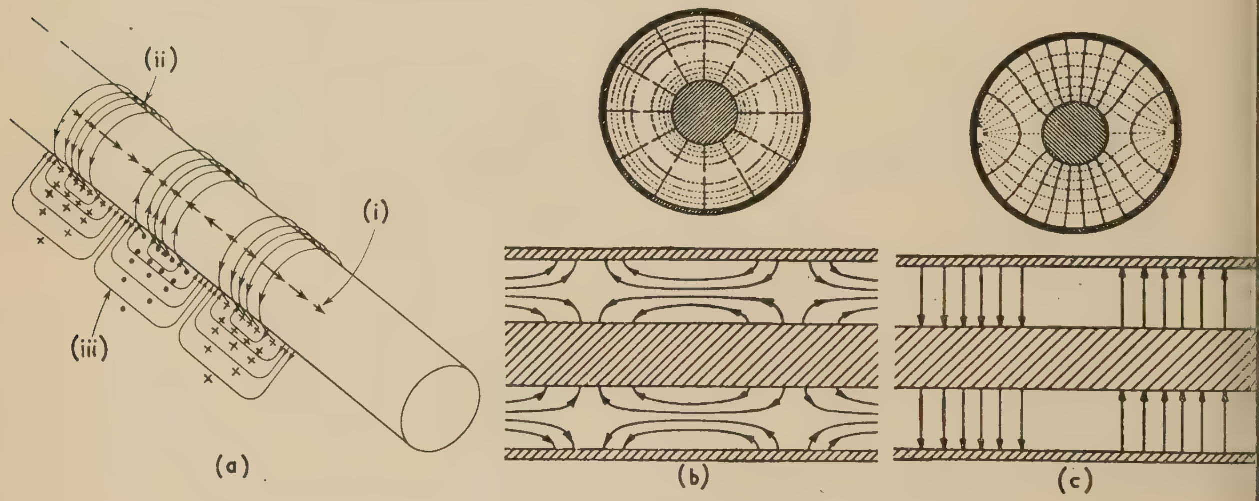


Fig. 2. Electric and magnetic field distributions concerned in the surface wave system

(*a*) Field distribution for the surface wave.
  (i) conduction current lines; (ii) *H* lines; (iii) displacement current lines.
  + = *H* lines going into paper; ● = *H* lines emerging from paper.

(*b*) Cross-section and longitudinal views of TM_{01} coaxial mo
  ——— = *E* lines; – – – – = *H* lines.

(*c*) Cross-section and longitudinal views of TE_{11} coaxial mo

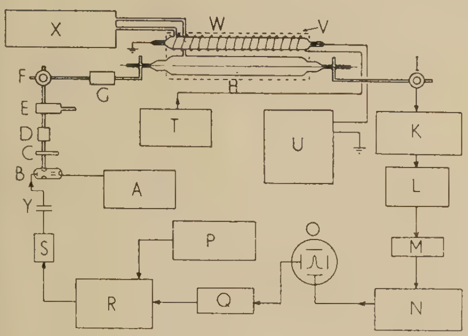
18 dB at 15 mm and 25 dB at 5 mm, there being higher resistive losses in the wire at high frequencies. Copper was chosen instead of platinum since it has much better conduction properties. The copper can readily be replaced if it corrodes. A platinum wire of the same diameter increased the overall losses by about 10 dB.

This cell is now suitable for the production of free radicals and other molecules by flash photolysis *in situ*, or by application of an r.f. discharge. It has a very small amount of exposed metallic surface which could aid catalytic recombination of the radicals.

THE MODULATION AND AMPLIFICATION SYST

Fig. 3 is a block diagram of the spectrometer. The mi wave source is a klystron (Raytheon type 2K33 or E.I type R9518) used directly over the frequency range 20–36 kMc/s, or in conjunction with a crystal harm generator similar to the type described by King and Gor for higher frequencies. Detection is by a silicon cry mounted with adjustable contact in the same way as in harmonic generator.

A sawtooth waveform, of frequency variable from a 50 c/s to 5 kc/s, is applied to the reflector of the klyst sweeps the frequency of the microwaves over about c/s. It is also applied to the X-plates of an oscilloscope. higher frequencies of sweeping are required to give uate coverage of absorption lines of substances of life- of the order of 10^{-3} s. An r.f. sinusoidal waveform of ency 600 kc/s is superposed on this sawtooth waveform. oidal modulation is used in preference to square-wave the small advantages to be gained by using the latter[(8)] offset by the difficulties of producing a good square- of sufficient amplitude (order of 100 V) at this frequency.



g. 3. Block diagram of source modulation spectrometer

klystron power pack; *B*, klystron; *C*, tuning element; attenuator; *E*, calibrated wavemeter; *F*, harmonic generator; filter section; *H*, absorption cell; *I*, crystal detector; *K*, pedance matching unit and pre-amplifier; *L*, main R.F. plifier; *M*, detector; *N*, audio-amplifier and R–C filters; oscilloscope; *P*, 600 kc/s sine wave oscillator; *Q*, cathode llower; *R*, modulation waveform mixer; *S*, cathode follower; triggering circuit; *U*, high voltage source; *V*, white-coated flector; *W*, discharge tube; *X*, vacuum system; *Y*, blocking capacitor.

r.f. waveform is produced by a Franklin oscillator and perposed on the sawtooth in a cascode type of circuit. amplitudes of the sawtooth and the r.f. waveforms may aried independently or together. The adjustment of the amplitude is critical for optimum performance of the trometer.

he frequency-modulated microwave power, after trans- sion through the cell, is detected at the crystal, and an orption line acts as a discriminator to convert the uency-modulated power into an amplitude-modulated al at the detector. Thus an amplitude-modulation r.f. lifier can be used. Two amplification systems are lable. The first is suitable for high-speed work. It has re-amplifier of low noise design, incorporating a type Y7 triode working in cascode following the crystal, and ollowed by the main r.f. amplifier which has three stages a voltage gain of about 100 dB. Modified commercial IFT 11 coils, capacitatively coupled and double-tuned, used to obtain a flat response curve over a 3 dB band- th of 240 kc/s about the central frequency of 600 kc/s. ching the varying impedance of the crystal detector to pre-amplifier is difficult over this frequency range. To rd some impedance matching, the rectified microwave er is fed to the pre-amplifier through an auto-transformer a Q of 2–3. The coaxial lead from the detector to the amplifier is doubly screened to avoid direct pick-up from 600 kc/s oscillator, and from various discharges used in cal production. Its self-capacity is tuned out in the sforming circuit.

he bandwidth of 240 kc/s was used for the following reason. At a sawtooth frequency of 5 kc/s sweeping the klystron over 20 Mc/s, an absorption line of width about 3 Mc/s is swept over in roughly 3×10^{-5} s. To reproduce the shape of such a line faithfully, experiments have been made which show that at least the first three of its Fourier components must be passed by the amplifying system without loss. These components will appear in the detected signal as sidebands of the carrier frequency (600 kc/s). Hence the minimum bandwidth required to accommodate both sidebands is in the region of 200 kc/s. There is an upper limit to the r.f. modulation frequency which can be used, determined by the width of the absorption line being studied. When the modulation frequency is of the order of the line width, the line splits into a number of smaller components. This effect was predicted by Karplus,[(9)] and has been observed in a Stark modulation microwave spectrometer.[(10)] Line widths of about 1 Mc/s are usual in gaseous absorptions at approximately 10^{-2} mm of mercury. Fig. 4 shows the Karplus effect in the present apparatus when the pressure (and hence the line width, since this is largely determined by pressure broadening) is reduced from approximately 10^{-1} to approximately 10^{-3} mm of mercury. The frequencies of modulation and the bandwidth chosen are about the optimum ones for reconciling the conflicting demands of high sawtooth frequency and width of absorption line.

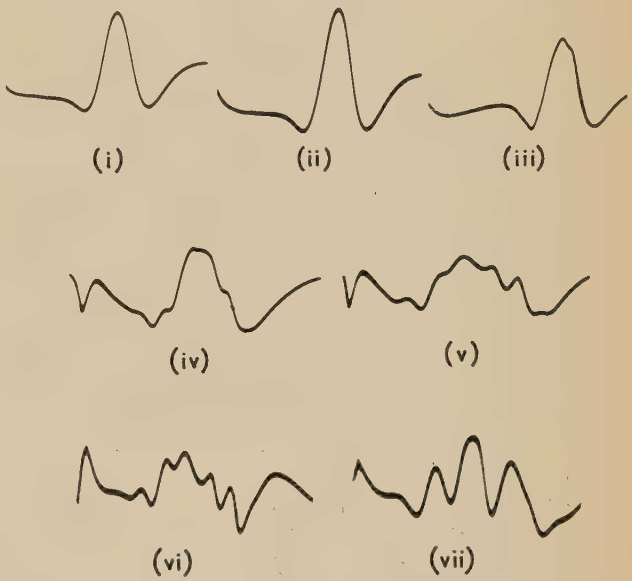

(i) (ii) (iii)
(iv) (v)
(vi) (vii)

Fig. 4. OCS ($J = 3 \rightarrow 4$) line at 48 652 Mc/s. Intensity $= 4{\cdot}4 \times 10^{-4}$ cm^{-1}. The series (i)–(vii) shows the effect of progressive reduction of pressure from approximately 10^{-1} to approximately 10^{-3} mm of mercury. The line breaks up into a number of components as the pressure is decreased, since the line width becomes comparable with the r.f. modulation frequency

The r.f. amplifier is followed by a diode detector and audio-frequency amplifier. Since the extreme sidebands of the detected signal up to ±100 kc/s carry an appreciable amount of the signal, conventional R–C filtering in the diode detector stage would not be sufficiently selective. For this reason, series-tuned filters of high Q at 600 kc/s are used to shunt the anode loads in the a.f. stages. The a.f. amplifier also has variable high- and low-pass R–C filters to provide discrimination against reflexions and discontinuities arising in the waveguide section, and to filter the slower variations of the output of the klystron.

An alternative amplifier system more suitable for low-speed work, as, for example, with steady-state concentrations of free radicals arising from continuous discharges, has been designed. The crystal detector is followed by a pre-amplifier similar in design to that described by Good.(11) This incorporates a series-tuned input circuit, and a type 12AY7 triode valve working in cascode. The circuit combines good impedance matching with low noise. It is followed by a narrow bandwidth r.f. amplifier, the overall bandwidth of the whole system being in the region of 5 kc/s. This is the lowest figure obtainable with the Q of the present type IFT 11 coils. A conventional diode detector circuit followed by an audio-frequency amplifier with a series of R–C filters appropriate to this narrower pass-band conducts the signal from the r.f. amplifier to the oscilloscope display. This system (called amplifier *B*) gives the spectrometer a sensitivity about ten times higher than that using the high-speed amplifier (amplifier *A*).

SENSITIVITY OF SPECTROMETER

The spectrometer has been calibrated over the range of 20–70 kMc/s by observations on absorption lines of various gases—carbon oxysulphide, ammonia, sulphur dioxide, methyl alcohol and oxygen. The minimum absorption detectable depends on the amount of power available, which is necessarily lower in the region covered by harmonic generation. Fig. 5 shows some lines observed with the narrow-band amplifier *B*, from which a sensitivity of about 10^{-7} cm^{-1} is apparent. Fig. 6, relating to the wide-band amplifier *A* shows somewhat reduced sensitivity in the same microwave region (24 kMc/s). Absorption coefficients of molecular lines tend to increase roughly as the square or even as the cube of the frequency, so that decreasing sensitivity towards higher microwave frequencies is largely offset, and is not a serious disadvantage. Fig. 6 also shows that no serious effects are introduced when the sawtooth sweep frequency is increased from 50 c/s to 5 kc/s. However, an increase to 10 kc/s did give a much reduced signal/noise ratio.

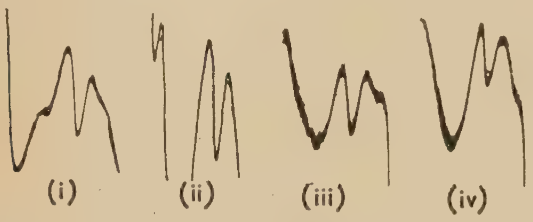


Fig. 5. Weak lines of OCS observed in the surface-wave absorption cell, with narrow-band amplifier. Pressure approximately 10^{-1} mm of mercury

(i) $J = 1 \rightarrow 2$ at 24 356 Mc/s. Intensity $= 4\cdot4 \times 10^{-6}$ cm^{-1}.
(ii) as (i) with line shape improved by passage of more high-frequency components.
(iii) $J = 1 \rightarrow 2$ at 24 254 Mc/s. Intensity $= 8\cdot7 \times 10^{-7}$ cm^{-1}. Conditions as in (i).
(iv) $J = 1 \rightarrow 2$ at 24 248 Mc/s. Intensity $= 5\cdot9 \times 10^{-7}$ cm^{-1}.

The performance of this instrument compares quite well with that of more conventional spectrometers which use very low sawtooth sweep frequencies. Such instruments, with sweep speeds of the order of 1 c/s, give minimum detectable absorptions in the region of 10^{-8} cm^{-1} at about 24 kMc/s. The increase in bandwidth necessitated by increasing the sweep speed by a factor of 1000 would reduce the sensiti of these instruments by a factor of about thirty.

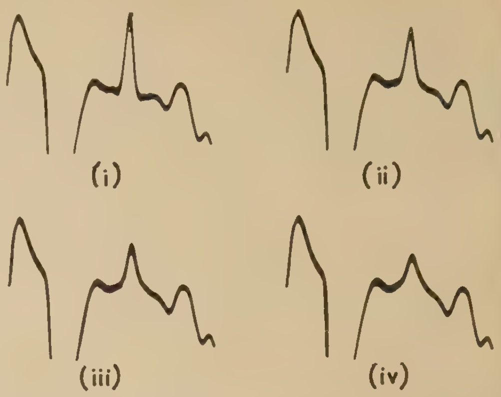


Fig. 6. Typical OCS lines observed in the surface-wa absorption cell, with wide-band amplifier. Pressur approximately 10^{-1} mm of mercury

(i) $J = 1 \rightarrow 2$ line at 24 326 Mc/s. Intensity $= 5\cdot5 \times 10^{-}$ cm^{-1}. Sweep frequency = 5 kc/s.
(ii) $J = 1 \rightarrow 2$ line at 24 356 Mc/s. Intensity $= 4\cdot4 \times 10^{-}$ cm^{-1}. Sweep frequency = 5 kc/s.
(iii) $J = 4 \rightarrow 5$ line at 60 814 Mc/s. Intensity $= 8\cdot7 \times 10$ cm^{-1}. Sweep frequency = 50 c/s.
(iv) As (iii) with sweep frequency = 5 kc/s.

PRODUCTION OF FREE RADICALS

Three methods of production of free radicals have considered, and have been catered for in this apparatus.

(i) Flash photolysis, in which a very intense flash of lig of short duration, produces photolysis of the gas in absorption cell, giving a burst of free radicals, the cc centration of which decays more or less rapidly. T techniques of this are well-established. In the present instan a quartz discharge tube 3 m in length is used, in which capacity of 15 μF charged to a maximum voltage of 20 is discharged, dissipating up to 3000 J in about 200 μs. T tube, 20 mm in diameter, is filled with argon at 7 cm mercury pressure, and is laid horizontally alongside microwave absorption cell in a cylindrical container coa with a white reflector on the inside.

Difficulty was experienced with interference from the spa type of trigger discharge used at first. This produced serio blocking in the amplifiers in spite of heavy screening, a ruined the crystal contacts. A new type of trigger w developed which caused negligible interference, operating external modification of the field between the charg electrodes of the flash tube. A loose copper helix is wou round the flash tube (about 1 turn/in.). One end of this left free, and the other connected by coaxial cable to o end of the secondary winding of a television output tra former, the other end of which is earthed. The primary the transformer is in the anode circuit of a beam tetro valve. A thyratron operated by a microswitch momentar cuts off the beam tetrode, and a voltage pulse of about 8 and a few microseconds in duration is applied to the spi trigger. This rapidly modifies the field in the flash tube a value beyond breakdown, and the main discharge ensu Great care is necessary to eliminate effects of mechani shock from the flash discharge, in particular in the mounti of possibly microphonic components in the amplifiers.

(ii) A high frequency discharge in the absorption cell. helical electrode, similar to that of the flash trigger, is wou und the absorption cell, and connected in the same way. e trigger circuit is now run repetitively, the thyratron being scharged about 10^3 times/s. This produces a glow discharge ncentrated about the central wire which carries the microves, and decomposes any gas present into atomic or olecular fragments. This system has been found to be ost useful in the introductory work on short-lived substances. steady state concentration of free radicals is built up, only ing away when the discharge is switched off, or when the aterial in the absorption cell is completely reacted to give al products not affected by the discharge.

(iii) A system is being built whereby molecules can be bjected to various forms of electrical discharge, and the oducts pumped continuously through the absorption cell.

PRELIMINARY RESULTS

Preliminary results have been obtained with the fairly ort-lived substance carbon monosulphide (CS), obtained y decomposition of carbon disulphide (CS_2). This is, of urse, not a free radical because it has no odd electron nd has a singlet ground state. The spectrum of CS is ready known,(1) with a rotational transition ($J = 0 \rightarrow 1$) at 8 991 Mc/s. This line appears quite strongly, as shown in ig. 7, when the continuous trigger system is used. The half-life of CS in this cell is of the order of 10 s at an initial pressure of about 10^{-1} mm of mercury. The line becomes weaker with continuous running of the trigger due to formation of a solid polymer of CS, together with sulphur, on the walls of the cell. Complete decomposition of a sample of carbon disulphide occurs in about 10 min.

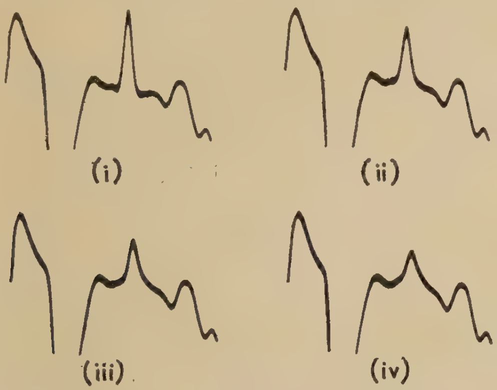


Fig. 7. Carbon monosulphide ($J = 0 \rightarrow 1$) line at 48 991 Mc/s. The decay of carbon monosulphide produced by high-frequency discharge in carbon disulphide vapour at approximately 10^{-1} mm of mercury is shown, at various times from switching off the discharge

(i) $t = 0{\cdot}0$ s; (ii) $t = 5{\cdot}0$ s; (iii) $t = 15$ s; (iv) $t = 30$ s.

Attempts to produce CS by flash photolysis of carbon disulphide were unsuccessful, probably through use of a Pyrex cell, rather than a quartz one. The present cell would be barely capable of transmitting light of sufficiently short wavelength for photolysis of carbon disulphide. Nevertheless, an interesting result to be discussed at length elsewhere, was obtained, in that about ten flashes were sufficient to reduce the concentration of carbon disulphide in the cell to such a level that application of the continuous trigger to the residue was unable to excite the CS spectrum, although no CS was observed as a result of the flashes. Probably the flash induces a decomposition of the carbon disulphide via optical excitation alone, without direct decomposition. Work is currently proceeding on the OH and ClO radicals.

REFERENCES

(1) Dousmanis, G. C., Schawlow, A. C., Sanders, T. M., and Townes, C. H. *Phys. Rev.*, **89**, p. 1158 (1953); Dousmanis, G. C., Sanders, T. M., and Townes, C. H. *Phys. Rev.*, **100**, p. 1755 (1955).
(2) Mockler, R. C., and Bird, G. R. *Phys. Rev.*, **98**, p. 1837 (1955).
(3) Costain, C. C. *Canad. J. Phys.*, **35**, p. 241 (1957).
(4) Norrish, R. G. W., and Thrush, B. A. *Quart. Rev. Chem. Soc* (*London*), **10** (2) (1956) (a general review).
(5) Gordy, W., Smith, W. W., and Trambarulo, R. F. *Microwave spectroscopy*, p. 7 (London: Chapman and Hall Ltd., 1953).
(6) Gobau, G. *J. Appl. Phys.*, **21**, p. 1119 (1950).
(7) King, W. C., and Gordy, W. *Phys. Rev.*, **90**, p. 319 (1953).
(8) Gordy, W., and Kessler, M. *Phys. Rev.*, **72**, p. 644 (1947).
(9) Karplus, R. *Phys. Rev.*, **73**, p. 1027 (1948).
(10) Townes, C. H., and Merritt, F. R. *Phys. Rev.*, **73**, p. 1249 (1948).
(11) Good, W. E. *Scientific paper No.* 1538 (East Pittsburgh, Penn.: Westinghouse Research Laboratories, 1950).

X-ray absorption microanalysis with fine-focus tubes

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A point focus X-ray tube has been used as a source for microanalysis by the X-ray absorption method. Transmission measurements on selected specimen areas of 2–10 μ diameter are possible, with wavelengths chosen by a crystal and a proportional counter. Comparison of the transmitted intensities at different wavelengths gives quantitative information on the mass thickness of elements present in the area examined. The ultimate mass sensitivity varies with the position of the element in the periodic table but is usually in the range 10^{-10}–10^{-12} g for elements of $Z > 15$. The application of the method to the determination of calcium is described.

The development of the X-ray absorption method for hemical analysis on an ultra-micro scale has been due argely to Engström(1) and Lindström,(2) who have used uantitative microradiographic techniques to determine the omposition of very small areas in thin sections of biological material. In their investigations conventional X-ray tubes and photographic recording were employed. The use of X-ray tubes with very fine foci for chemical analysis by both absorption and fluorescence techniques has already been discussed,(3, 4) and some experimental work has been reported.[4] This paper describes the application of a point focus tube and electrical recording methods to absorption microanalysis, with particular reference to the determination of calcium in the mass range 10^{-9}–10^{-10} g. The experimental details, including an analysis of errors, are described here. The results obtained in studies of the distribution of calcium in animal teeth and in certain minerals will be published elsewhere.

In the technique evolved by Engström and Lindström two contact microradiographs of the specimen are recorded at X-ray wavelengths on the high and low energy sides of either the *K* or *L* absorption discontinuity of the element whose thickness is required. Subsequent microphotometer measurements on the developed emulsions then give the X-ray transmissions of corresponding areas in the two photographs. These measurements can be performed on areas of only a few microns in diameter, and the results are related to the thickness of the element according to equation (1).

$$\frac{T_1}{T_2} = \exp - \left\{ m\left[\left(\frac{\mu}{\rho}\right)_{\lambda_1} - \left(\frac{\mu}{\rho}\right)_{\lambda_2}\right] + m'\left[\left(\frac{\mu}{\rho}\right)'_{\lambda_1} - \left(\frac{\mu}{\rho}\right)'_{\lambda_2}\right]\right\} \tag{1}$$

Here T_1 and T_2 are the measured transmissions at wavelengths λ_1 and λ_2, m is the mass/cm^2 of the element and m' the mass/cm^2 of the matrix in which it occurs: $(\mu/\rho)_{\lambda 1}$ and $(\mu/\rho)_{\lambda 2}$ are the mass absorption coefficients of the element at λ_1 and λ_2, and $(\mu/\rho)'_{\lambda 1}$ and $(\mu/\rho)'_{\lambda 2}$ are the corresponding coefficients for the matrix material. The relationship is illustrated by Fig. 1. If the wavelengths used lie very close to the absorption edge, $m'\left[\left(\frac{\mu}{\rho}\right)'_{\lambda_1} - \left(\frac{\mu}{\rho}\right)'_{\lambda_2}\right]$ is small and may be negligible. In cases where this quantity is not small and is also unknown, it is necessary to make measurements at four wavelengths, from which the height of the absorption discontinuity may be extrapolated on a logarithmic plot of the results.[5]

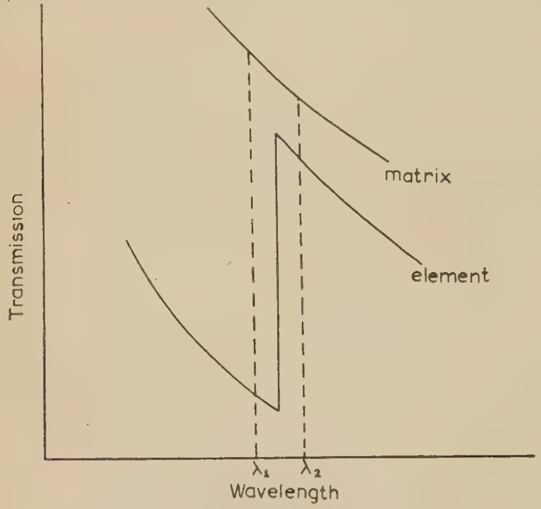

Fig. 1. Transmission conditions near an absorption discontinuity

The difficulties associated with the photographic technique may be partially overcome by the use of electrical recording, and experiments with a conventional X-ray source and Geiger counter have recently been reported by Engström, Lagergren and Lundberg.[6] Since the X-ray source us in this method is large, the area examined must be defin by an aperture placed in contact with the specime Measurements on areas from 100 μ to a few millimetr square are described. Rosengren[7] has used a proportion counter to determine the transmissions of areas 1·8 μ diameter in the wavelength range of 6–12 Å. It is doubtfu however, whether accurate estimates of the thickness of a element can be obtained with a proportional counter alon except in special cases where the absorption is predominate due to that element, owing to the limited energy resoluti of this device.

An X-ray tube with a very small focal spot allows the u of projection geometry as shown in Fig. 2. Here the targ to specimen distance *t*, may be as little as 0·5 mm, so that a aperture of 1 mm diameter in a plane at 15 cm, *D*, from th target will transmit X-rays which have passed through a area of 3 μ diameter in the specimen. An analyser crystal an a counter set above the aperture may then be used to recor the intensity of selected wavelengths. The very high specifi loading of the target (approximately 100 kW/mm^2), and th small spot size and target to specimen distance (1 μ an 0·5 mm respectively), combine to produce a very high X-ra flux through the specimen and a high primary magnificatio in the aperture plane. It is thus possible to determin directly the transmission of precisely located areas in th specimen without using very small apertures.

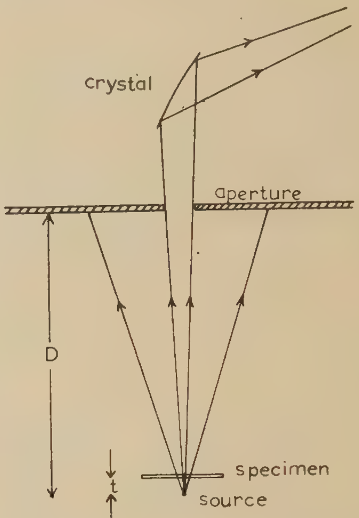

Fig. 2. Geometry of projection with point source

EXPERIMENTAL

The X-ray tube used in this work was similar to tha previously described by Cosslett and Nixon,[8, 9] except tha it employed only one magnetic lens giving an X-ray sourc of 1–2 μ in diameter. The general arrangement of th apparatus is shown diagrammatically in Fig. 3. X-ray generated in the thin foil target pass through the specime and into the spectrometer *via* the 6 μ Melinex windo which is attached to the end of the rubber tube *R*. This tub and the body of the spectrometer may be filled with hydroge to reduce absorption at long wavelengths. The flexibility o the tube allows it to be moved to one side for introductio of a fluorescent screen. The exit window of the spectromete is also of Melinex foil and is separated by a 1 cm air ga n the proportional counter which can be positioned so to receive the diffracted beam. The spectrometer is lly mounted on a platform above the magnetic lens so : the position of the aperture remains fixed with respect he target of the X-ray tube. This aperture thus defines angular width of the beam entering the spectrometer, hence for a given target to specimen distance, the area pecimen examined.

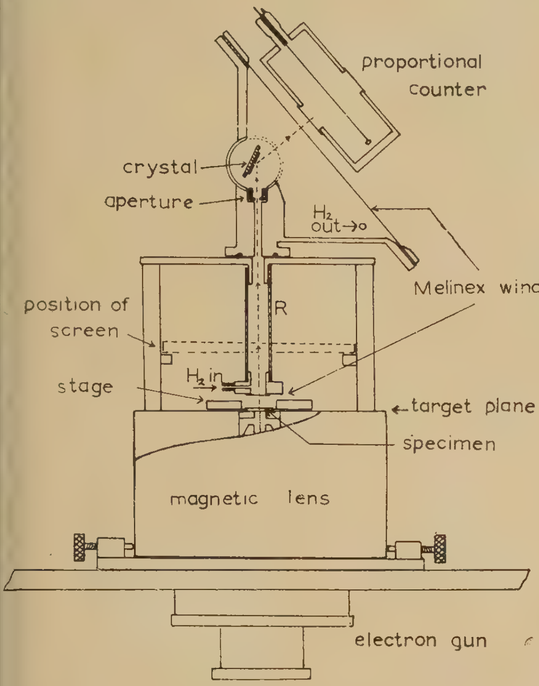

Fig. 3. X-ray tube and spectrometer (diagrammatic)

rystal geometry. In order to increase the reflected ensity, a curved crystal has been used. The full angular lth of the beam through the aperture can be as much as or 2°, whilst the angle over which Bragg reflexion occurs a flat crystal at a given wavelength is much smaller than s value. Consequently only a narrow strip of a flat stal will reflect monochromatic radiation, no matter how ge the aperture, and although the intensity reflected from continuous spectrum increases with aperture size, the olution falls. It is easily shown that if a crystal is mounted in Fig. 4, for rays OA and OB to be reflected at the same agg angle, then α must equal β, and further that $R = d\,.\,\mathrm{cosec}\,\theta$ for small angles of α. If the crystal is used in the same way as a flat crystal, the angular relationship $\alpha \doteq \beta$ is only true for one value of θ. However, the curved crystal may be used for a range of angles on either side of this setting, provided that some loss of resolution can be tolerated. The number of crystals needed to cover a given angular range thus depends on the aperture and the resolution required. With the present spectrometer an increase of intensity of approximately seven times has been obtained by this method. In some wavelength regions the intensity in the continuous spectrum is sufficient to allow automatic plotting of the transmission in the neighbourhood of an absorption edge, as shown in Fig. 5. In other cases, notably at the wavelengths required for the determination of calcium, the intensity available is lower, and it is then more convenient to measure the transmission at two or more fixed wavelengths on the high and low energy sides of the absorption edge. Ideally in such measurements the target is chosen to have characteristic lines near the absorption edge of the element to be determined, but where this is not possible the continuous spectrum must be used.

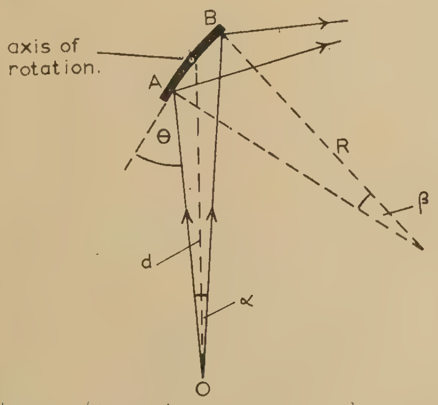

Fig. 4. Geometry of curved crystal

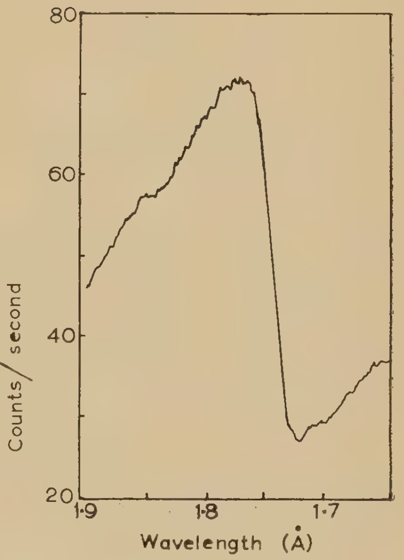

Fig. 5. Automatic plot of K absorption edge of iron

Recording system. It is clear from equation (1) that as $m \rightarrow 0$, the ratio $T_1/T_2 \rightarrow 1$, and moreover that the error in m becomes increasingly dependent on the errors in the measured transmissions as m decreases. It is therefore necessary to provide accurate compensation for variations in intensity in the radiation incident on the specimen. The monitor counter technique commonly employed in X-ray diffraction equipment, is not convenient in this instance, mainly due to the difficulty of intercepting part of the incident beam when the specimen is in position.

The method used was based on the fact that in order to determine the thickness of an element when the matrix effect is negligible or can be calculated, it is only necessary to measure the ratio T_1/T_2. The separate transmissions are not required, provided that the ratio of the intensity of the two wavelengths remains constant at the target, and can be measured with no absorber present.

In the present form of the apparatus, the spectrometer crystal is arranged to alternate between two fixed angular positions, corresponding to the two wavelengths on either side of the absorption edge. By means of a relay operated in synchronism with the solenoid controlling the crystal position, the corresponding pulses from the proportional counter are routed to two separate scaling units. The two totals recorded, when corrected for the background count and the ratio with no specimen, give directly the ratio of transmissions. Fig. 6 is a block diagram of the apparatus. The amplified pulses from the proportional counter pass to

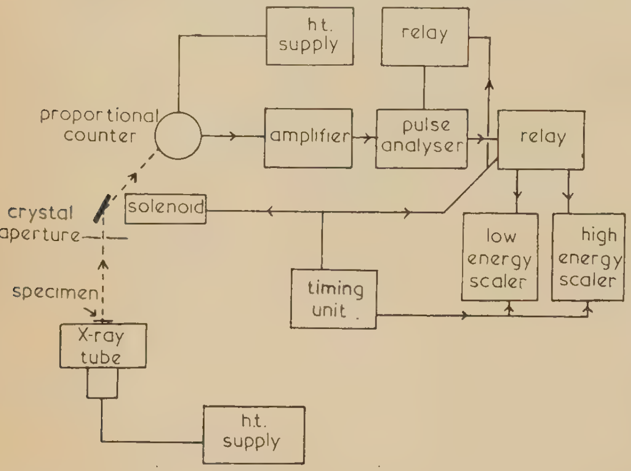

Fig. 6. Block diagram of two channel recording apparatus for absorption analysis

an analyser which selects those due to quanta of wavelength near the absorption edge, and largely eliminates the effect of those arising from higher order reflexions. The relay attached to the analyser, which is also operated synchronously with the crystal, serves to switch the bias voltage so that the position of the analyser channel remains constant in relation to the energy reflected by the crystal. The second relay, as described above, simply transmits the high and low energy pulses to the two scalers. The interval between movements of the crystal is 7·5 s and the total measurement time is normally several minutes, so that drifts in the primary intensity are effectively eliminated.

Positioning of the specimen. Except in the case of sections showing a very high contrast, it is difficult to see detail in the shadow image on a fluorescent screen. An electron microscope grid is therefore mounted on the section so that after location of a particular area in an optical microscope, the same area can be positioned on the stage of the X-ray apparatus by reference to the shadow image of the grid bars. The specimen and grid are mounted over a hole punched in an aluminium foil at the centre of a simple stage that can be placed either on the optical microscope, or on the top surface of the magnetic lens, between screws which allow a fine adjustment of its position relative to the X-ray source. The fluorescent screen is arranged to slide in on a plane about 2·5 cm above the target, and is located against three fixed points to an accuracy of approximately $\pm 50\,\mu$. Thus for a target to specimen distance of 0·5 mm, an accuracy of $\pm 0{\cdot}1$ mm in the location of the image on the screen cross wires corresponds to an accuracy of $\dfrac{\pm 0{\cdot}1 \times 0{\cdot}5}{25} = \pm 2\,\mu$ in the specimen plane.

The cross-wires of the screen are aligned with the spectrometer aperture with the aid of a $10\,\mu$ aperture placed on the specimen stage. After adjustment of the stage to a position so that the X-ray beam produced by the $10\,\mu$ aperture also passes through the spectrometer aperture, the screen inserted and the cross-wires moved so that their intersect falls in the centre of the image of the $10\,\mu$ aperture. W this aperture replaced by the specimen it is thus possible, estimating the co-ordinates in a $100\,\mu$ grid square, to loc the area to be analysed with an error not exceeding ± This error could be reduced to about $\pm 2\,\mu$ by increas the target-to-screen distance and by using a reference gri finer mesh. The stability of the position of the X-ray sou is such that after initial alignment, no further adjustment the cross-wires was found necessary during running peri of several hundred hours.

The micro-determination of calcium. The appara described has been used in studies of the distribution calcium in animal teeth(10) and in some naturally occurr minerals.(11) The transmission ratios in $10\,\mu$ areas polished sections 10–60 μ thick were measured for the t wavelengths 3·00 Å and 3·14 Å. There are no target mater suitable for the production of characteristic radiation in region of the calcium absorption edge, and aluminium was found to be the most reliable target material for generation of 3 Å continuous radiation. Count rates 2000/min were obtained in the wavelength bands selected a pentaerythritol crystal from a $12\,\mu$ aluminium foil with accelerating voltage of 25 kV and a target current of ab $10\,\mu$A. The crystal consisted of a flake of pentaerythri which was curved by pressing it with a ground steel plate the appropriate radius into a thin layer of wax on a sc support.

The systematic errors of the method, which cause observed transmission ratio for a given calcium thickness differ from that given by equation (1), were investigated measurements on cleavage flakes of gypsum ($CaSO_4 . 2H_2$ This mineral has a very constant composition, and as a res of its perfect cleavage, it is possible to obtain flakes wh

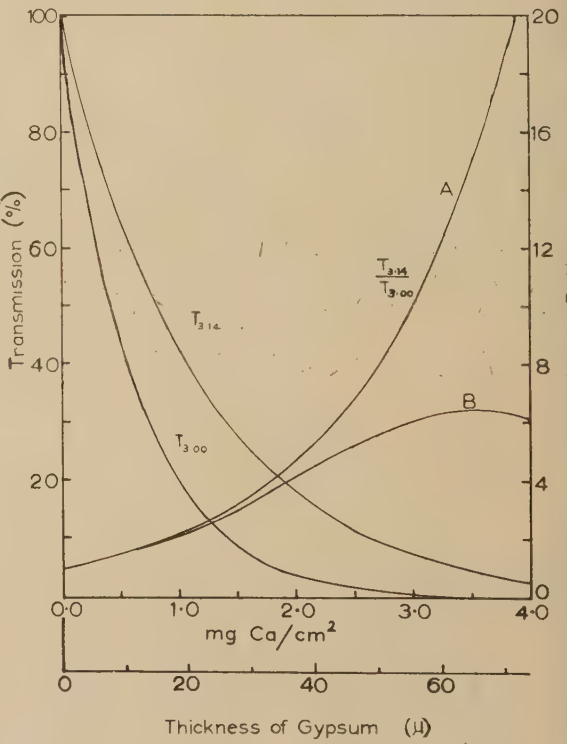

Fig. 7. Transmission of gypsum at 3·14 Å and 3·00 Å as a function of thickness

e steps 10–100 μ wide, ranging in thickness from a few rons upwards. Selected areas on two such flakes were d as standards, their true thickness being determined with olarizing microscope and a Berek compensator. These er measurements were carried out in sodium light, for ch the birefringence of gypsum is 0·0092.(12)

he X-ray transmission of gypsum, at 3·00 Å and 3·14 Å, ulated as a function of thickness, is shown in Fig. 7. curve A represents the ratios of these transmissions. In se and subsequent calculations, mass absorption coeffints have been taken from the tables of Victoreen.(13) The -ray thickness" of calcium in each of the steps, obtained m the observed transmission ratios and the curve A, is wn plotted against the optically determined thickness in . 8. The deviation of the experimental values from the

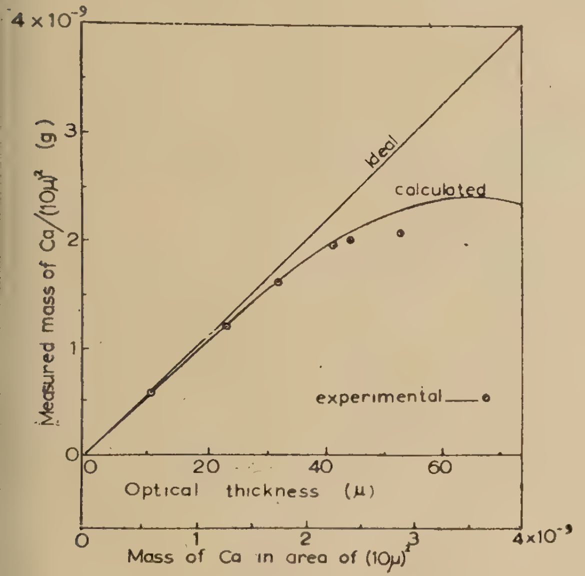

Fig. 8. Comparison between X-ray and optical measurements on small areas of gypsum cleavage flakes

al straight line increases non-linearly with thickness, due the fact that under the conditions of these measurements, radiation reflected from the analyser crystal is not comtely monochromatized. The high working voltage of the ray tube, dictated by the intensity requirements, results in considerable production of the second harmonic of the band, and this is not completely eliminated by the prortional counter and pulse analyser. Some Compton ttering also occurs at the crystal, with the result that liation with an effective wavelength of considerably less n 3 Å reaches the counter. The presence of a low energy il" in the pulse height distribution from the counter, ses a number of these scattered quanta to give rise to ses of height equivalent to 3 Å. The intensity of the ttered radiation was measured by determining the count e in the 3 Å pulse analyser channel with the crystal turned that the diffracted beam fell outside the counter aperture. was found to be 1·15% of the 3 Å count. Measurement the attenuation of the scattered radiation by filters of own thickness and composition gave an effective wavegth of 1·57 Å. The fraction of the 3 Å count which was to 1·5 Å second-order radiation was also determined d found to be 0·24%. In order to simplify computation, effect of the second-order reflexion and the scatter are sidered together, the total count rate being 1·39% of the 3 Å rate and the weighted mean of the wavelengths 1·56 Å.

This impurity radiation considerably increases the apparent transmission of thick specimens at 3·00 Å since for calcium $(\mu/\rho)_{1\cdot56} \ll (\mu/\rho)_{3\cdot00}$. The transmission at 3·14 Å is not affected to the same extent so that the observed ratio is reduced. The absorption coefficients for gypsum calculated from Victoreen's tables are given in the table.

Absorption coefficients for gypsum

	Wavelength (Å)		
	3·00	3·14	1·56
(μ/ρ) *gypsum*	376·8	199·0	66·1

The transmission ratio in the presence of the impurity radiation is then given by:

$$\frac{T_1'}{T_2'} = \frac{(T)_{3\cdot14} + 0\cdot0139(T)_{1\cdot56}}{(T)_{3\cdot00} + 0\cdot0139(T)_{1\cdot56}} \tag{2}$$

where $(T)_\lambda$ represents the transmission of gypsum at wavelength λ. The most striking property of this relationship (curve B in Fig. 7) is the complete reversal of slope at about 3·5 mg/cm², where $(T)_{3\cdot00}$ and $0\cdot0139(T)_{1\cdot56}$ are almost equal. The relationship between optical and X-ray thickness of gypsum which would be expected under these conditions can be obtained directly from the curves A and B, and is represented by the full curve in Fig. 8. The curve agrees closely with the experimental values up to 2·5 mg/cm.² Beyond this point the theoretical curve fails to account entirely for the experimental results, probably due to inaccuracy in the determination of the effective wavelength of the scattered radiation. Other possible causes of the deviations have been examined, but in the useful working range, factors such as diffraction and fluorescence within the specimen can be shown to produce only small errors.

The range of the method in the case of calcium is thus approximately 0·1–2·5 mg/cm² for materials whose transmission is comparable to that of gypsum. The transmission of some silicate minerals and of hydroxylapatite in bone is greater in relation to the calcium content so that appreciable deviations from the corresponding theoretical curves do not occur until thicknesses of about 3·5 mg/cm² calcium are reached. In practice the specimen can normally be ground to a thickness such that its calcium content falls within the range of the method. However, a more careful design of the proportional counter to give increased sensitivity and better energy resolution, and a lower voltage on the X-ray tube would undoubtedly reduce the intensity of the impurity radiation and so extend the range. The importance of using a counter which does not show an appreciable escape peak has already been stressed.(14)

Errors due to statistical fluctuations of count rate. In the absence of impurity radiation, the range of the method is determined by the accuracy with which the transmission ratio can be measured in a given time interval. The fractional error in the ratio, expressed in terms of the standard deviation, σ_R, is given by

$$\frac{\sigma_R}{R} = \pm\left[\left(\frac{\sigma_S}{S}\right)^2 + \left(\frac{\sigma_A}{A}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

where σ_S/S is the fractional error for the measurement with the specimen and σ_A/A is the error for the uninterrupted beam.

The standard deviation of any single measurement will be $\pm(N_i t)^{\frac{1}{2}}$ where N_i is the count rate at wavelength λ_i and t the time for which it is recorded. Under the conditions obtaining in the calcium measurements, $\sigma_A/A = \pm 0{\cdot}01$ or $\pm 1\%$. The fractional error in the final ratio in this case will thus be given by:

$$\frac{\sigma_R}{R} = \pm\left[\frac{1}{N_1 t} + \frac{1}{N_2 t} + (0{\cdot}01)^2\right]^{\frac{1}{2}} \qquad (4)$$

or

$$\frac{\sigma_R}{R} = \pm\left\{\frac{1}{N_0 t \exp\left[-\left(\frac{\mu}{\rho}\right)_{\lambda 1} m_0\right]} + \frac{1}{N_0 t \exp\left[-\left(\frac{\mu}{\rho}\right)_{\lambda 2} m_0\right]} + (0{\cdot}01)^2\right\}^{\frac{1}{2}} \qquad (5)$$

where N_0 is the count rate at 3 Å with no specimen, and $(\mu/\rho)_{\lambda 1, \lambda 2}$ and m_0 are the absorption coefficients and mass thickness of the specimen (element + matrix) respectively. Taking N_0 as 2000/min and t as 25 min, and substituting the appropriate values of the constants for gypsum, we obtain the numerical relationship between m and the percentage error in the ratio, as shown in Fig. 9.

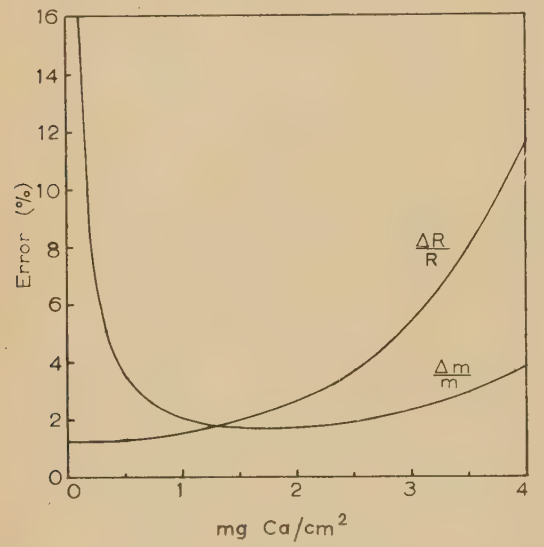

Fig. 9. Errors in ratio and thickness for gypsum, calculated for a measurement time of 50 min

The error in the ratio can be related to the error in m by rewriting equation (1) with $m' = k \,.\, m$ and differentiating to obtain dR/R (where $R = T_1/T_2$) when

$$-\frac{dR}{R} = \left\{\left[\left(\frac{\mu}{\rho}\right)_{\lambda 1} - \left(\frac{\mu}{\rho}\right)_{\lambda 2}\right] + k\left[\left(\frac{\mu}{\rho}\right)'_{\lambda 1} - \left(\frac{\mu}{\rho}\right)'_{\lambda 2}\right]\right\} . \, dm \qquad (6)$$

For gypsum $k = 3{\cdot}30$, so that $dR/R = 766 \,.\, dm$. Thus a 1% error in the ratio corresponds to a difference of 0·013 mg in the value of m. By combining this result with equation (5) we obtain the second curve of Fig. 9. At the lower end of the range the accuracy is limited by the fact that as $m \to 0$, $R \to 1$, and at the upper end by the low intensity of the transmitted radiation. All measurements have been made in the central region where the error does not exceed ±3%.

DISCUSSION

The application of the method to the determination of calcium has clearly demonstrated certain sources of inaccuracy, some of which would become much less import in the case of elements for which higher X-ray intensi are available. In the method described, where only t wavelengths are used, it is necessary to know the specim thickness and nature of the matrix in order to obtain unambiguous measure of the thickness of a particu element. In some biological systems calcium occurs hydroxylapatite in a purely organic matrix. It is easy show that, even in the presence of the impurity radiati a change of 100% in the normal thickness of the orga matrix associated with a given amount of calcium within working range will produce only a 3% change in estimated calcium content. Only an approximate knowle of the composition and density of the matrix is theref required in order to provide complete compensation for effect.

In systems where no such information is available, measu ments may be performed at more than one wavelength either side of the edge, so that the true height of the d continuity may be obtained by extrapolation. In so instances the target can be chosen to provide a group characteristic L lines suitable for this purpose. At wa lengths for which a crystal of high resolution can be us two transmission measurements can be made as in present method, but very close to the absorption edge that the effect of the matrix becomes vanishingly small.

The area examined in these experiments is 10 μ in diamet but this may be reduced to the source size (1–2 μ), either mounting the specimen closer to the target, or, if suffic intensity is available, by reducing the size of the spectrome aperture.

The method is thus capable of providing information ab the micro-distribution of one or more elements in the prese of a matrix which may vary both in thickness and in co position. It is not well suited to qualitative analysis unknown material except when the number of possi elements is limited. The very sensitive micro-fluorescen technique, in which a fine beam of X-rays is used to exc secondary characteristic radiation in a small area of specim is much better suited to the latter problem. It is possi that the absorption corrections necessary to obtain quanti tive information from the fluorescence measurements m be determined by techniques similar to those described this paper.

ACKNOWLEDGEMENTS

I should like to thank Dr. V. E. Cosslett for suggesti this research and for his continued advice and encourageme I am also greatly indebted to Dr. W. C. Nixon and Dr. Duncumb for many helpful discussions, and to Mr. J. Ful and Mr. R. H. Pryor for their assistance in the constructi of the spectrometer. This work has been supported by grant from the Department of Scientific and Industr Research, which I gratefully acknowledge.

REFERENCES

(1) Engström, A. *Acta Radiol., Suppl.* 63 (1946).
(2) Lindström, B. *Acta Radiol., Suppl.* 125 (1955).
(3) Zeitz, A., and Baez, A. V. *Proceedings of Symposi on X-ray Microscopy and Microradiography, Ca bridge*, 1956, p. 417 (New York: Academic Press In 1957).
(4) Long, J. V. P., and Cosslett, V. E. *Proceedings Symposium on X-ray Microscopy and Microrad graphy, Cambridge*, 1956, p. 435 (New York: Acaden Press Inc., 1957).

Ref. 1, p. 25.

ENGSTRÖM, A., LAGERGREN, C., and LUNDBERG, B. *Exp. Cell Res.*, **12**, p. 592 (1957).

ROSENGREN, B. *Nature* [*London*], **117**, p. 1127 (1956).

COSSLETT, V. E., and NIXON, W. C. *J. Appl. Phys.*, **24**, p. 616 (1953).

COSSLETT, V. E., and PEARSON, H. E. *J. Sci. Instrum.*, **31**, p. 255 (1954).

(10) RÖCKERT, H. *Acta Odontologica Scandinavia*, **16**, Suppl. 25.

(11) LONG, J. V. P., and MCCONNELL, J. D. C. *Min. Mag.* (in the press).

(12) HUTCHINSON, A., and TUTTON, A. E. H. *Z. Kryst.*, **52**, p. 223 (1913).

(13) VICTOREEN, J. A. *J. Appl. Phys.*, **19**, p. 855 (1948).

(14) LONG, J. V. P. *Proceedings of Symposium on X-ray Microscopy and Microradiography, Cambridge*, 1956, p. 628 (New York: Academic Press Inc., 1957).

An airborne infra-red solar spectrometer

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A grating spectrometer developed for installation in a Canberra aircraft is described. An electronically operated heliostat maintains an image of the sun on the entrance slit. Resolution of 2 cm^{-1} is achieved with a lead sulphide detector. Preliminary results are given for the 2 μ region for heights up to 45000 ft.

e infra-red solar spectrum has been the subject of intensive dy from observatories on the earth's surface. By inition, however, it is only possible to make observations regions of the spectrum where some solar energy reaches earth. Large portions of the infra-red region are com- tely obscured, even at high mountain observatories, by absorption bands of water vapour and carbon dioxide. order to make observations in these regions it is necessary work at high altitude. The much reduced absorption ich might be expected at 45000 ft is illustrated in Fig. 1.

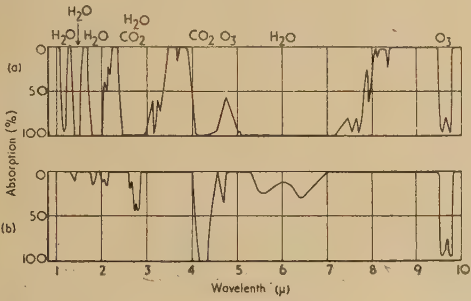

Fig. 1. Absorption of solar energy by the atmosphere (*a*) at ground level; (*b*) expected at 45000 ft.

this height the path-lengths of carbon dioxide and water pour between the observer and the sun are about one-tenth d one-thousandth respectively of their values at sea level. By investigating the solar spectrum from a high-flying craft, quantitative data will be obtained about the con- tration of water vapour and the rarer atmospheric con- tuents, such as the oxides of nitrogen, at these levels. e amount of infra-red solar energy absorbed by the high nosphere will be measured; this is an important parameter consideration of its thermal balance.

THE SPECTROMETER

In order to resolve the main absorption lines in infra-red ectra, an optical resolution of about 1 cm^{-1} is required. High resolution has two advantages: firstly, the positions and intensities of absorption lines can be determined with greater accuracy, and secondly, the envelope curve, corresponding to the radiation incident outside the atmosphere, will be easier to construct. This means that a much lower level of absorption can be detected. Although a resolution of 1 cm^{-1} can be obtained using a refined prism instrument, it is easier to obtain by using a grating, and, if the grating is suitably blazed, with much greater efficiency.

Since the spectrometer is to observe the solar spectrum from an aircraft, a means of maintaining a steady image of the sun on the entrance slit is required, or else a method of recording the spectra during the brief intervals that the aircraft is facing in the right direction. Jones and Roberts$^{(1)}$ and Hargens$^{(2)}$ have used the second method. Its disadvantage is that, if any appreciable region of the spectrum is to be recorded, the resolution will be low. For instance, with a chopping frequency of 5 kc/s, if 1000 cm^{-1} are to be recorded in 0·1 s, each interruption represents 2 cm^{-1}. Not only does this factor limit the resolution, but in order to record at this speed a wide-band amplifier must be used, which decreases the signal-to-noise ratio. Thus, to obtain the resolution required, it is necessary to use a servo-system to follow the sun, and to keep a steady image on the entrance slit of the spectrometer.

Other observations have been made of the infra-red solar spectrum from aircraft by Yarnell and Goody,$^{(3)}$ Johns Hopkins University$^{(4)}$ and from a balloon up to 100000 ft by Murcray and others.$^{(5)}$ All these workers used prism instruments coupled with heliostats, and an optical resolution of about 0·1 μ or 100 cm^{-1} at 3 μ was obtained. The heliostat used in the balloon instrument has been described by Edwards and others.$^{(6)}$

The optical system of the spectrometer is shown in Fig. 2. A Merton–N.P.L. grating, 4 × 3 in., having 7500 lines per inch is used. With this grating the region 1–5·5μ can be covered. Other gratings will be used at longer wavelengths. The two mirrors M_6 and M_7 associated with the grating are spherical and of 50 cm focal length. The premonochromator uses a calcium fluoride prism of 15° angle. This is coupled to the grating by means of a cam on the grating table. The second and third slits can be adjusted by micrometers; the entrance slit is fixed at 1 mm wide.

The spectrometer is installed in the unpressurized part of the aircraft, and thus is quite inaccessible during flight. Sunlight reaches the spectrometer through a hole in the skin of the aircraft which is covered with a sheet of gauze. All adjustments and checks have to be made by remote control from the pressure cabin. A fault in the spectrometer or heliostat cannot be corrected until the aircraft has landed; thus it is important that the operator has sufficient information to diagnose the fault correctly while still airborne. The instrumentation and control system has been designed with this in mind.

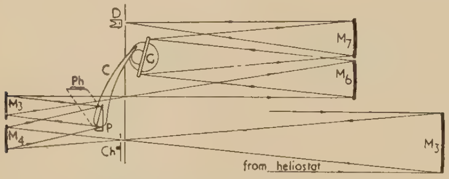

Fig. 2. Optical system of spectrometer

Mirrors: M_3, 15 × 15 cm, 70 cm focal length; M_4, M_5, 6 × 6 cm, 25 cm focal length; M_6, M_7, 9 × 8 cm, 50 cm focal length; *Ch*, chopper, 750 c/s; *Ph*, monitor photocell; *P*, fore-prism; *G*, grating; *C*, cam drive for prism; *D*, detector, lead sulphide or lead telluride cell.

The diffraction grating is mounted on a table which is rotated by a 360/1 worm drive. This has been specially constructed by Weyers Bros. to be accurate over a 90° traverse to better than 20″ of arc. The worm is rotated through a further reduction of 30/1 by a slave Selsyn motor. The master Selsyn is located in the control unit in the cabin, and is driven through a gear box by a 3000 rev/min synchronous motor powered from a 50 c/s supply. Six speeds can be selected in the gear box corresponding to speeds of grating rotation of 0·2, 0·4, 0·8, 1·6, 3·2 and 12·8 minutes of arc per second. At 3 μ, 1′ of arc is equivalent to 2 cm^{-1}. The master Selsyn motor drives a revolution counter which indicates the grating position to within 2′ of arc. Another revolution counter is connected to the slave Selsyn in the spectrometer; this makes it possible to check that no slip is occurring between the Selsyn motors.

The spectrometer was set up on the mercury green line in the first and the second order. The wavelength of this line being known, and the law connecting grating angle with wavelength being $n\lambda = k \sin\theta$, where n is the order being observed, the grating constant k can be determined. calibration has been checked against water-vapour absorp lines of known wavelength; the checking has been pe within the accuracy of the counter.

The chopper which interrupts the light signal at 750 c driven by a 3000 rev/min synchronous motor powered f a 50 c/s supply. The frequency stability of the 50 c/s sup installed in the aircraft was not sufficient, and so a sta 50 c/s oscillator, using a tuning fork, was built to supply motor. The circuit is shown in Fig. 3. To obtain the po necessary for the motor, two transistor push-pull circuit parallel had to be used.

Since the spectrometer is installed in the unpressuri part of the aircraft, it will be in surroundings where temperature may fall to −50° C. Such a change in tempe ture might cause considerable misalinement of the opt system, and would also expose the equipment to the dan of condensation when the aircraft returned to a region higher temperature. The instrument has therefore been insulated thermally, and heaters controlled by thermos have been installed underneath the spectrometer. To ens that the heating system is functioning satisfactorily, resista thermometers in different parts of the spectrometer indic their temperatures on the control unit in the cabin.

The quantity of water vapour in the upper atmosphe very small, and could easily be exceeded by the amount in spectrometer itself if precautions were not taken to keep very small. A large Dewar vessel containing liquid nitro is connected by a pipe to the spectrometer. A small heate installed in this container so that approximately 8 l./min very dry nitrogen is blown into the spectrometer.

THE HELIOSTAT

The heliostat is required to correct for random aircr movements when flying on a fixed course, and also initia to search for and lock on to the sun. So that the light in to the spectrometer shall not vary, control is required w a maximum error of about 12′ of arc. The maxim deviation of the aircraft, which is a Canberra, from a strai course is ±2° in yaw and roll. The minimum period these oscillations of the aircraft about its mean course about two seconds.

The optical system of the heliostat is shown in Fig. Sunlight falls on a plane mirror M_1 6 in. square, which c be turned about a horizontal axis parallel to the centre l of the aircraft, and is thus able to receive sunlight at a

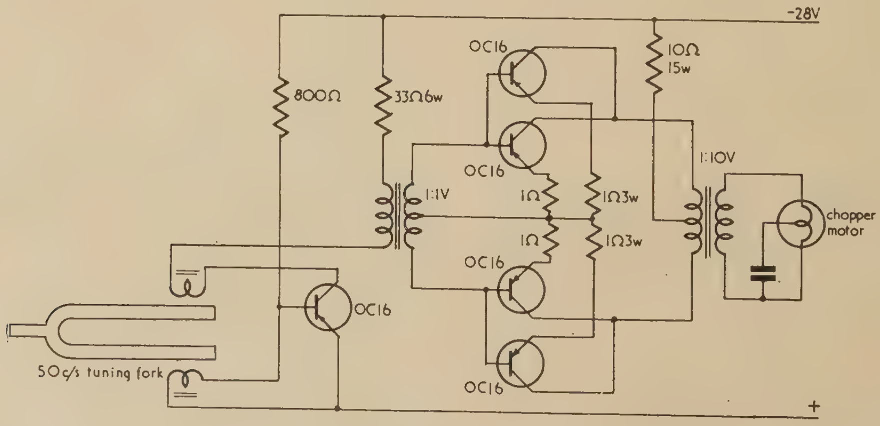

Fig. 3. Tuning fork oscillator for chopper motor

le of the sun's altitude. From this mirror light is reflected . similar mirror M_2 which can rotate about a vertical axis. ixed concave mirror M_3, of 70 cm focal length, gives an ge of the sun 6 mm in diameter on the entrance slit of spectrometer.

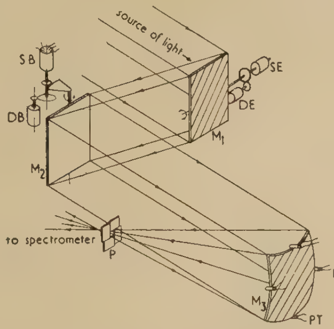

Fig. 4. Optical system of heliostat

M_1, elevation control mirror with elevation motor *DE* and elevation Selsyn *SE*; M_2, bearing control mirror with bearing motor *DB* and bearing Selsyn *SB*; M_3, concave mirror (see Fig. 2); *P*, photocells around input slit of spectrometer; *PT*, phototransistors.

At a distance of 5 cm in front of this slit, where the light am is about 15 mm square, four selenium barrier-layer otovoltaic cells are arranged as shown in Fig. 4. In the rmal position no light falls on the cells; the beam of light st fills the central hole. If the aircraft deviates from its urse, one of the photocells will be illuminated. The suing signal, suitably amplified, drives the appropriate irror to correct for the change of course.

It was found that the level of illumination on the photo-lls was much too great. The output of the photocells turated, with the result that the background illumination ve a signal which was a significant proportion of that from e sun's image. The performance of the cells was much proved by coating them with a layer of evaporated uminium transmitting about 20% of the incident light d reflecting the remainder. Under these conditions the lls give an output (into a resistance of 100 Ω) of about 2 mA with background illumination, and of about 1 mA ith the sun's image.

The mirrors are rotated by low inertia integrating motors, hich are small permanent-magnet d.c. motors built in a milar manner to moving-coil instrument movements. The advantages of these motors are low inertia (0·002 g cm^2), fast speed of response and good starting characteristics. The no-load speed of the motor with 24 V supply is 2000 rev/min. This speed can be attained when loaded with gear box and mirror with a 30 V supply. The gear box, which has been carefully adjusted and spring-loaded to keep backlash to a minimum, reduces the motor speed in the ratio 1000 : 1. The mirror shaft can thus be turned at 2 rev/min or 12°/s, which is more than adequate to deal with aircraft movements. To prevent the mirror movements becoming sluggish when exposed to the low temperatures in the unpressurized part of the aircraft, each gear box is thermally insulated and fitted with a 10 W heater and thermostat. A resistance thermometer in each gear box indicates its temperature on the control unit in the cabin. It is thus possible to check that they are warm enough.

To amplify the photocell signal and drive the motors, a conventional valve amplifier was at first constructed using a vacuum photocell input and driving the motors directly. It was found that the motors were driven from too high an impedance to provide damping, and at high gains the system was unstable. To overcome this, a low impedance output was provided by using Velodyne generators to drive the mirror motors. This system worked satisfactorily but was rather heavy.

A simpler and much lighter amplifier has been built using transistors; the circuit is shown in Fig. 5. The output of the selenium photocells, and hence the gain of the system, is controlled by the 20 kΩ resistor. The 560 Ω resistors compensate for background illumination by adjusting the bias of the second stage. The voltage applied to the motor from the amplifier for small deviations of the light beam from its central position is shown in Fig. 6. The impedance across the motor is 300 Ω, which is small enough compared to the armature resistance of 800 Ω to prevent over-running and oscillation.

The heliostat was tested in the laboratory on an oscillating table capable of movement up to ±2° at frequencies up to 2 c/s. A lamp and condenser lens were used to represent the sun; the reduced brightness of this source compared to the sun was compensated for by replacing the aluminized photocells with plain ones. The servo-system performed satisfactorily at angular speeds up to 10°/s. This is much greater than the rates of turn and roll encountered in an aircraft.

The photocells are sensitive to deviations of the incident sunlight of up to 4° from the central position. In order to

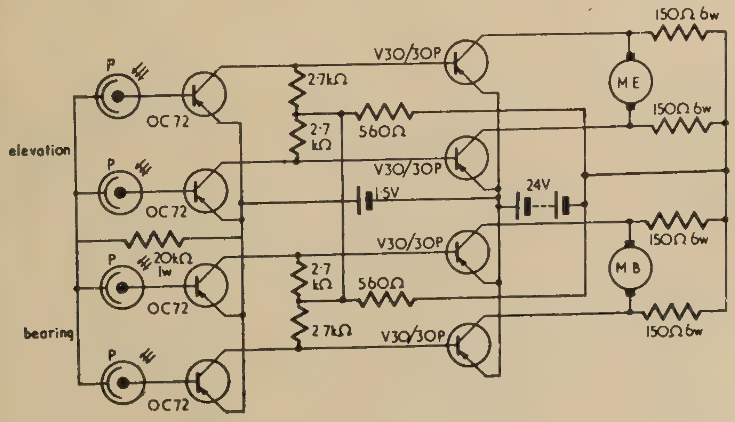

Fig. 5. Circuit diagram of heliostat

P, photocells; *ME*, elevation motor; *MB*, bearing motor.

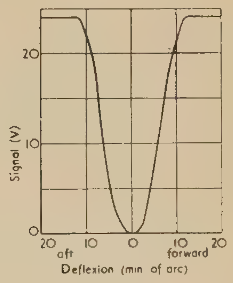

Fig. 6. Output of heliostat amplifier for small deflexions of light image from central position (supply voltage, 24 V)

set the mirrors initially in approximately correct positions, a manual control is installed in the control unit in the cabin so that each mirror can be moved in either direction or connected to the servo-amplifier. The position of each mirror is transmitted by Selsyn motors (see Fig. 4) to indicators on the control panel in the cabin. The position of the second mirror, which corrects for errors in bearing, is also transmitted to an indicator on the pilot's instrument panel. The pilot can then fly so that the mirror is central in its traverse; this means that, when the heliostat is in circuit, the sun is accurately on the port beam. To make the initial procedure of finding the sun easier, four phototransistors have been mounted around the concave mirror (see Fig. 4). When light falls on any of these a relay is operated which lights a neon lamp on the control unit. At least one of the neon lamps will be lit, providing the beam of sunlight is within 10° of its correct position. The operator can then manually adjust the mirrors until light falls on the photocells. Meters on the control panel are connected to the output of the heliostat amplifier and inform the operator when the sun's image is on the photocells. He then switches over to servo-control.

A check on the performance of the servo-system is provided by a meter on the control unit directly connected to a selenium photocell inside the spectrometer. This photocell (see Fig. 2) receives light reflected from the front surface of the prism. The meter reading should be steady during normal operation of the instrument indicating constant light input to the spectrometer. The steadiness of the signal during an actual flight is demonstrated in the "no scanning" portions of Fig. 9.

THE DETECTOR

A lead sulphide cell is the detector in the spectral region below 3 μ. For measurements above 1·8 μ a germanium filter is placed over the cell to remove spurious radiation at short wavelengths. For work at wavelengths longer than 3 μ a lead telluride cell will be used. This is more difficult to install since the lead telluride cell has to be mounted in a vertical position and cooled with liquid nitrogen. The arrangement is shown in Fig. 7. A resistance thermometer *R*, in the upper part of the lead telluride cell *T*, indicates on a ratiometer in the control unit in the cabin when the liquid nitrogen has fallen below the lower end of the resistor. The solenoid valve *S* is then closed, sealing the vacuum flask *F* from the outside air. Normal boiling in the vacuum flask then pushes liquid nitrogen through the Dewar tube *D* into the telluride cell, and fills it up. When the cell is full the solenoid valve is opened and the siphoning ceases.

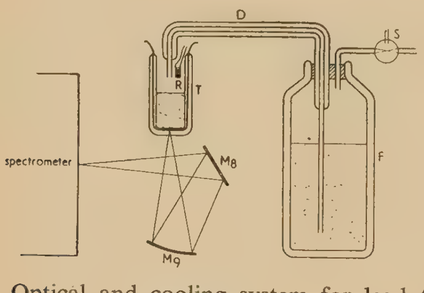

Fig. 7. Optical and cooling system for lead telluride detector

S, solenoid valve; M_8, plane mirror; M_9, concave mirror; *T*, lead telluride cell; *R*, resistance thermometer; *D*, Dewar tube; *F*, vacuum flask containing liquid nitrogen.

To avoid loss of signal in the long lead from the detec to the amplifier, a cathode follower circuit is built in spectrometer housing adjacent to the cell. The signal, wh is modulated at 750 c/s, is then fed into a tuned ampli in the aircraft cabin. This amplifier follows the design Brown.(7) The tuning, which was originally at 800 c/s, v changed to 750 c/s to avoid pick-up from the aircraft 400 inverters. The earthing of the detector, cathode follower a amplifier had to be modified by trial and error to elimin the various sources of electrical noise. During flight noise of amplifier or cell is very little greater than th encountered in the laboratory.

The output of the amplifier is fed to a Honeywell–Bro pen recorder installed in the cabin where it can be seen the observer. This recorder is a self-balancing potentiome instrument. The powerful pen drive is unaffected by aircr movement and can cross the chart in one second. T recorder is fitted with a ball pen which works quite sat factorily at high altitude.

A pair of contacts which close twenty times per revoluti are attached to the worm shaft driving the grating ta These contacts control a relay actuating another pen on t edge of the chart of the Brown recorder. A mark is ma for each 3′ of arc rotation of the grating.

The amplifier output, and also the output of the monit photocell in the spectrometer, are recorded simultaneous on a photographic film recorder. Thus if the light input the spectrometer should vary owing to malfunctioning of t heliostat, the spectra obtained can be adjusted appropriat

INSTALLATION IN AIRCRAFT

The location of the various units in the aircraft is sho in Fig. 8. Since very little space is available in the pressu cabin, most of the equipment had to be accommodated the bomb-aimer's position in the nose. The operator lie prone on his right side, his legs beside the pilot's seat, th control unit and amplifier facing him, and the recorde ahead of him.

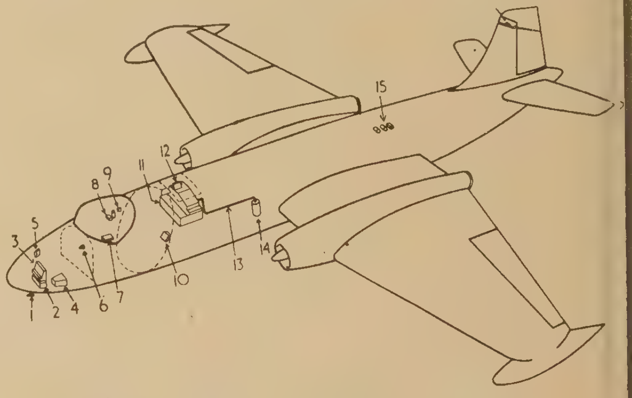

Fig. 8. Location of equipment in aircraft

(1) air temperature thermometer; (2) amplifier power unit; (3) pen recorder; (4) 750 c/s amplifier and control unit; (5) thermometer indicator; (6) Selsyn on pilot's panel; (7) heliostat amplifier and tuning fork oscillator; (8) hygrometer; (9) film recorder; (10) recorder amplifier; (11) spectrometer; (12) heliostat; (13) dry nitrogen pipe; (14) liquid nitrogen container; (15) 50 and 400 c/s inverters.

The normal aircraft electrical supplies of 28 V d.c. an 115 V 400 c/s have been used where possible. However to avoid substantial modification to the Honeywell–Brow

order, a 50 c/s inverter was installed in the rear compart-
nt of the aircraft to supply power for this. Aircraft
ctrical and mechanical engineering standards are much
her than those normally encountered in the laboratory,
d considerable work and extensive tests were needed to
ng the instrumentation up to the stringent safety require-
nts of aircraft engineers. The weight of the equipment
s to be kept as low as possible. Light alloy has been
ed extensively; for instance, the casting on which the
ectrometer is mounted is constructed from magnesium
loy. The spectrometer with heliostat weighs about 100 lb.
ll the electronic gear is mounted on anti-vibration mounts.
ounting of the spectrometer in this way, however, would
ean that it could oscillate relative to the aircraft at too
eat a rate for the heliostat to follow. The spectrometer
d heliostat are thus mounted on hard rubber pads which
e rigidly connected to the aircraft frame.

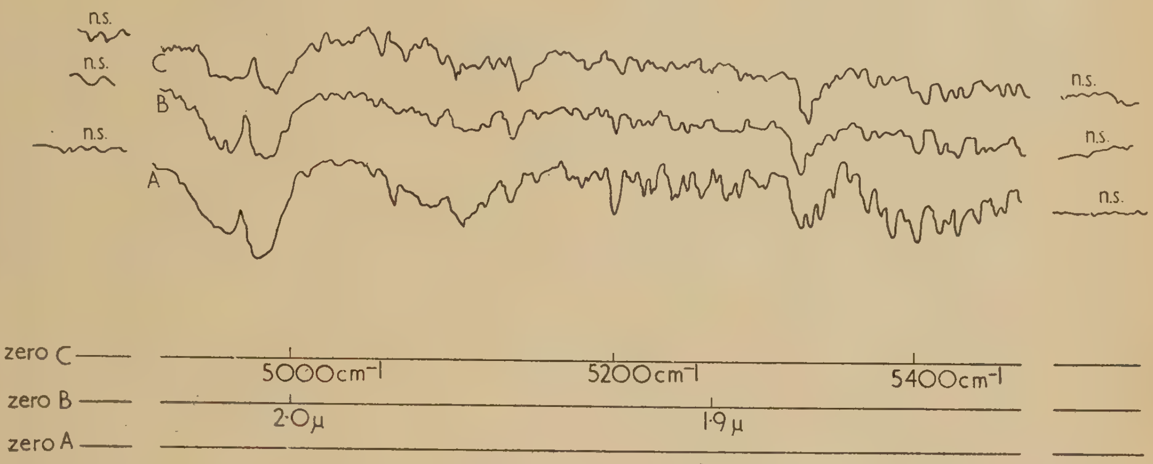

Fig. 9. Solar spectra at *A* 30 000 ft, *B* 40 000 ft and *C* 45 000 ft

n.s., not scanning.

AIRCRAFT MEASUREMENTS

Successful observations of solar spectra have been made
heights up to 45 000 ft. Tracings of the region 1·8–2·1 μ
different altitudes obtained at mid-day on 15 August,
57, are shown in Fig. 9. The 1·9 μ water vapour absorp-
on band, and 2 μ carbon-dioxide absorption bands are
early shown. It is clear that the water vapour absorption
rapidly disappearing at the higher altitudes. A path-
ngth of laboratory air containing only 7 μ of precipitable
ater vapour would give the same absorption as the record
btained at 45 000 ft. More extensive measurements over
e spectral region 1–8 μ are planned for the future, and will
e reported later.

ACKNOWLEDGEMENTS

This project was undertaken in consultation with the Gassiot Committee of the Royal Society as part of the International Geophysical Year programme of the Royal Aircraft Establishment.

The transistor circuits were designed by Mr. A. K. Walton; Mr. I. D. Birch constructed most of the electronic equipment and Mr. T. D. F. Hawkins acted as airborne observer. We also acknowledge the participation of many colleagues in the drawing office, workshops, installation and experimental flying departments of the Royal Aircraft Establishment.

REFERENCES

(1) Jones, F. E., and Roberts, V. *Proc. Roy. Soc. A*, **236,** p. 171 (1956).

(2) Hargens, C. W. *Rev. Sci. Instrum.*, **25,** p. 1162 (1954).

(3) Yarnell, J., and Goody, R. M. *J. Sci. Instrum.*, **29,** p. 352 (1952).

(4) *High Altitude Infra-Red Transmission of the Atmosphere* (Report by Johns Hopkins University, 1949).

(5) Murcray, D., Brooks, J., Murcray, F., and Shaw, C. *High Altitude Infra-Red Studies of the Atmosphere* (University of Denver, 1957).

(6) Edwards, H. D., Goddard, A., Juza, M., Maher, T., and Speck, F. *Rev. Sci. Instrum.*, **27,** p. 381 (1956).

(7) Brown, D. A. H. *J. Sci. Instrum.*, **29,** p. 292 (1952).

The influence of rate of cooling on the zeros of mercury-in-glass thermometers

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[*Paper received* 8 *May*, 1958]

A study of the effect of rate of cooling on the temporary depression of the zero of high-range mercury thermometers has been made from two points of view. It is concluded that if the cooling rate is sufficiently slow (about 15 h to cool from 400° C to room temperature) the temporary depression is completely suppressed. It is also concluded that from the point of view of a "permanence of range" or "bulb stability" test, the best discrimination between different batches of thermometers is obtained when the zeros are determined after slow cooling.

One of the chief sources of error in mercury thermometry is the instability of zero shown by glass thermometers. The zero changes are of two kinds: a slow drift known as the *secular change* and a thermal hysteresis effect known as the *temporary depression*. The temporary depression appears as a difference between zero readings taken before and immediately after heating, the second reading always being lower. This effect is a function of the elastic properties, and hence the composition, of the glass and the depression is of the order of 0·05° C per 100° C of heating for the normal glasses and 0·01° C for the borosilicate glasses. If the thermometer is left at air temperature for some days, the zero tends to return to its old value, though the recovery is sometimes only partial. The secular change normally takes the form of a slow rise of zero during storage, the rise being accelerated by exposure to high temperatures. The secular change also depends on the composition of the glass, but is above all affected by its thermal history. It is thus very much influenced by manufacturing techniques, especially the annealing procedure.

A test known as the "permanence of range" or "bulb stability" test is often carried out in order to assess the likely long-term stability of zero of high-range thermometers. Essentially this test consists of heating the thermometer to the maximum temperature of its range for a pre-determined time and observing the change of zero. In experiments carried out at the Koninklijke/Shell-Laboratorium, Amsterdam, and at the National Physical Laboratory it appeared that the results of this test could be appreciably affected by the rate of cooling of the thermometers. The following N.P.L. experiment illustrates the point.

Five thermometers were heated together in a copper block to a temperature of 370° C. Two, of English manufacture, were of Powell's normal (blue-stripe) glass and divided to 0·2° C and three were made in the U.S.A. of Corning normal glass, divided to 2° C. Heating was carried out for periods of about 120 h, and the thermometer corrections were determined from time to time against a platinum/rhodium-platinum thermocouple, using a potentiometer reading directly to 0·1 μV (equivalent to 0·01° C). Zero readings were taken immediately before each heating and again 48 h after completion of the cooling. The results are shown in Fig. 1.

The rise of reading at 370° C is indicated by full lines. The rises at zero are shown by broken lines, the slope of which has been drawn on the assumption that the whole of the rise took place uniformly while the thermometer was at the high temperature. Three series of observations were made. Before the first series of readings were taken the thermometers had been allowed to cool naturally in still air, and this procedure was followed at the end of the first series of heatings. The thermometer readings at 370° C rose rapidly at first and then much more slowly, while the rise 0° C (difference between the zero readings before and 48 after heating) does not reflect the full rise of reading whi took place in the thermometer in the furnace. At the end the second heating, during which the thermometers behav in a similar way, they were cooled slowly in the furnace about 12° C/h down to 120° C, and the observed zero ris now correspond closely with the rises in the reading of t thermometer in the furnace. It appeared likely that the rap cooling had produced a depression of the zero of eac thermometer, from which recovery was not complete in 48 and the rapid rise at the start of re-heating is caused by t recovery from this temporary depression.

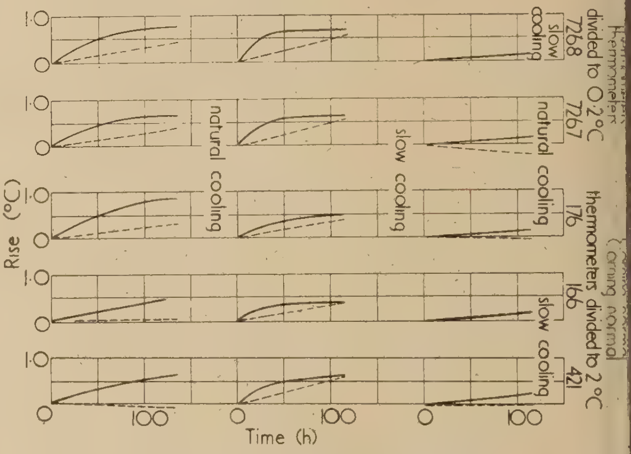

Fig. 1. Experiments on two English and three American thermometers in connexion with "permanence of range" or "bulb stability" test

——— rise at 370° C.; – – – – rise at 0° C.

The third series of measurements confirmed this suppos tion. The thermometers were now in the condition of havi been cooled slowly, and no abnormal rise in reading too place at the start of the heating. At the end, two of th thermometers were removed from the furnace and allowe to cool naturally, while the remaining three were cooled 12° C/h as before. Of the two English thermometers, th one which was cooled slowly gives exactly the same zero ri as the rise observed in the furnace, while the one coole naturally gives a zero nearly 0·4° C too low. The America thermometers were only divided to 2° C so that it is hard possible to detect a difference of less than 0·2° C betwee two rises. Bearing this in mind, the results obtained wi them in the third heating are inconclusive, but not inconsiste with the other results.

These results were in general agreement with experience at Koninklijke/Shell-Laboratorium, Amsterdam, and a ore detailed study of the effect, using both normal and rosilicate glasses, was then carried out in both laboratories.

EXPERIMENTS AT THE KONINKLIJKE/SHELL-LABORATORIUM, AMSTERDAM

The work at Amsterdam was designed to investigate fferent procedures for carrying out a permanence of range st, making changes in both duration of heating and rate of oling, in order to find the procedure which would give the eatest discrimination between the zero stabilities of various ermometers. To allow for differences in manufacturing chnique, the experiments were carried out in duplicate, oth German and English thermometers being used. The umbers in each batch were chosen so that a statistical alysis could be made with some validity, and in order to ing into the picture the effects of maximum temperature e tests were carried out with thermometers ranged 0 to 00° C and 0 to 400° C.

The experiments on the thermometers ranged 0 to 300° C ere carried out as follows. Eighty English and eighty erman thermometers, all made of Jena 2954‴ borosilicate ass, were placed in an electric tube furnace of 11 cm ternal diameter having about 8 cm of lagging round the ube. They were packed in powdered kieselguhr (diatomite) o as to enable them to be cooled slowly. Heating was arried out over a period of six hours up to a temperature of 35 ± 5° C and the furnace was then held at that temperature or 24 h. The equality of temperature of the bulbs of the hermometers was checked by means of thermocouples and ound to be within ±5° C tolerance. After 24 h, ten of ach kind of thermometer were removed from the furnace nd cooled down naturally in air (about 15 min). A further en of each kind were transferred to a similar furnace, already t 285 ± 5° C, and also filled with kieselguhr, and allowed o cool down in about 8 h to nearly room temperature. A imilar procedure was carried out with twenty thermometers of each kind after the heating had been extended to total times of 48, 72 and 96 h.

The zeros of the thermometers were re-determined immediately they had cooled to room temperature (either naturally or in the cooling furnace) and again at approximately daily intervals for at least thirteen days. No perceptible change of zero took place during the latter period. The mean zero rise of each group of ten thermometers was calculated, and also the standard deviations of the zero rises in each batch. The results are given in Table 1, which also shows the differences between the zero rises obtained with slow and rapid cooling for corresponding batches. On the average, slow cooling has produced a zero rise 0·06° C greater than rapid cooling, but this is scarcely significant. The standard deviation of the zero rises of individual thermometers in each group is of the order of 0·08° C, so that the standard deviation of the mean would be about 0·03° C and consequently that of the difference between two means would be about 0·05° C.

Similar tests were carried out with thermometers ranged 0 to 400° C, except that these were heated to 390 ± 5° C, and the results are given in Table 2. Here the difference between slow and rapid cooling is greater; the standard deviations have not increased to quite the same extent, so that the difference of 0·16° C is probably just significant.

Table 1. *Experiments at the Koninklijke/Shell-Laboratorium, Amsterdam*

Zero changes (° C) of thermometers of borosilicate glass after heating to 285° C

Origin of thermometer	*Duration of heating (h)*	*Rate of cooling*	*Mean zero rise: all observations*	*Standard deviation of individual thermometer*	*Difference between zero rises: slow minus rapid cooling*
England	24	rapid	0·06	0·06	
		slow	0·12	0·06	0·06
Germany		rapid	0·08	0·05	
		slow	0·16	0·07	0·08
England	48	rapid	0·05	0·07	
		slow	0·05	0·06	0·00
Germany		rapid	0·16	0·08	
		slow	0·12	0·07	−0·04
England	72	rapid	0·08	0·08	
		slow	0·14	0·13	0·06
Germany		rapid	0·21	0·11	
		slow	0·20	0·12	−0·01
England	96	rapid	0·08	0·04	
		slow	0·13	0·06	0·05
Germany		rapid	0·19	0·08	
		slow	0·46	0·21	0·27
			Mean difference		0·06

Table 2. *Experiments at the Koninklijke/Shell-Laboratorium, Amsterdam*

Zero changes (° C) of thermometers of borosilicate glass after heating to 390° C

Origin of thermometer	*Duration of heating (h)*	*Rate of cooling*	*Mean zero rise: all observations*	*Standard deviation of individual thermometer*	*Difference between zero rises: slow minus rapid cooling*
England	24	rapid	0·07	0·07	
		slow	0·29	0·12	0·22
Germany		rapid	0·18	0·12	
		slow	0·29	0·11	0·11
England	48	rapid	0·31	0·19	
		slow	0·36	0·19	0·05
Germany		rapid	0·28	0·19	
		slow	0·56	0·24	0·28
England	72	rapid	0·54	0·39	
		slow	0·47	0·15	−0·07
Germany		rapid	0·26	0·18	
		slow	0·46	0·25	0·20
England	96	rapid	0·35	0·24	
		slow	0·59	0·22	0·24
Germany		rapid	0·29	0·16	
		slow	0·56	0·16	0·27
			Mean difference		0·16

EXPERIMENTS AT THE NATIONAL PHYSICAL LABORATORY

The primary aim of the N.P.L. experiments was to determine how long it was necessary to allow for recovery from the temporary depression of zero when the thermometers had been cooled from a high temperature. Guillaume, writing in 1889 (*Traité pratique de la Thermométrie de Précision*, p. 137), says: "The time after which the stable position is reached depends, for a given glass, on the initial and final temperatures and on the direction and speed of the temperature change. The higher the temperature, the more quickly the stable state is reached; for the same final temperature the change is much more rapid with a rising than with a falling temperature. In particular, the recovery of the zero is much favoured by a very slow lowering of the temperature; on the contrary, when a thermometer is cooled suddenly its last stable state is maintained and the new one is sometimes only reached after a very long time."

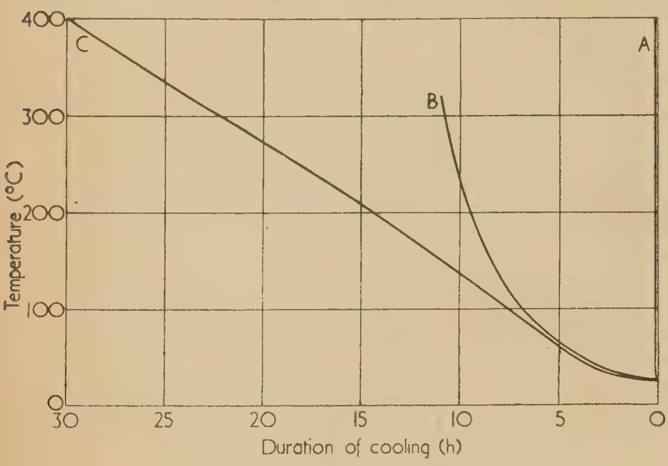

Fig. 2. Cooling rates for glasses under different conditions

A, by natural cooling in still air; *B*, by natural cooling in a furnace; *C*, by lowering the control point of the furnace controller at a steady rate.

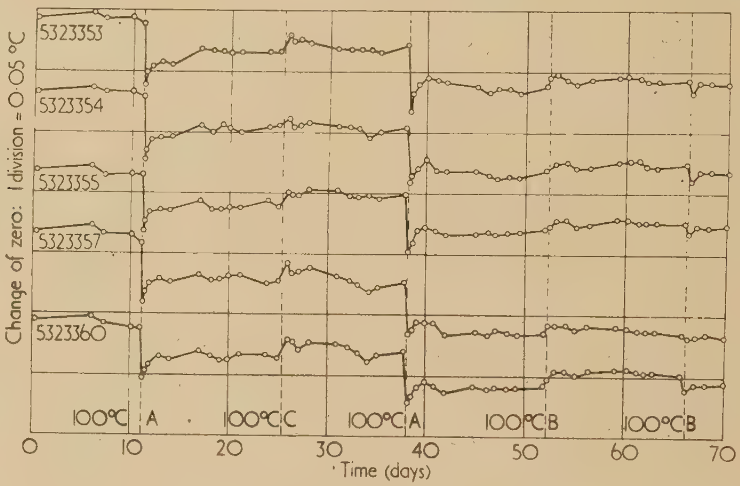

Fig. 3. Zero changes of thermometers made of Plowden and Thompson's normal glass

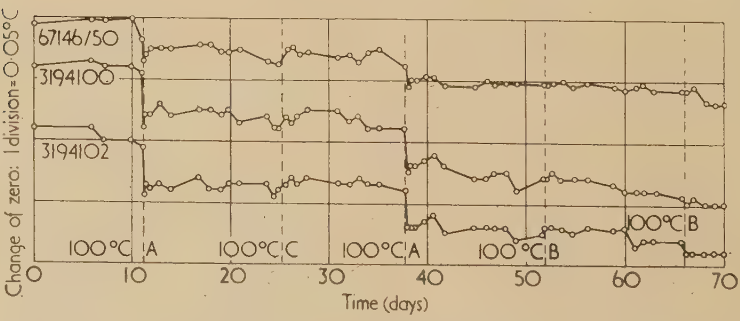

Fig. 4. Zero changes of thermometers of Jena 16''' glass (67146/50) and of Tomey's normal glass

In the N.P.L. experiments, the thermometers were heated vertically in an electric tube furnace having a tube of 4 cm internal diameter surrounded by 10 cm of lagging. The lower half of the tube was filled with a block of diatomite on which the thermometer bulbs rested, the temperature bei measured and controlled to about ±2° C with a platinum/1 rhodium-platinum thermocouple. The thermometers w only held at the maximum temperature for about an hour, order to minimize any permanent drift of zero so that t experimental results should give values for the tempora depression only. Moreover, the thermometers used we in most cases, old thermometers known to have good stabili

Three cooling rates were used, designated *A*, *B* and *C* Fig. 2. Rate *A* is given by natural cooling in still air a rate *B* by natural cooling in the furnace. Rate *C* was obtain by lowering the control point of the furnace controller (automatic potentiometer) at a steady rate of about 120 μV Owing to the non-linear e.m.f.-temperature calibration of t couple, this leads to a gradually increasing rate of cooli which is ultimately turned into a decrease as the natu cooling rate of the furnace becomes less than the controll rate. Consequently, curve *C* does not depart seriously fro a straight line when its whole length is considered. T experiments were carried out with normal glasses at 100, 3 and 360° C, and with the borosilicate glasses at 400° C.

Figs. 3 and 4 show experiments with thermometers normal glass. The thermometers of Fig. 3 (kindly lent Esso Research Ltd.) were to Institute of Petroleum specific tion IP32W, divided to 0·05° F, and were made of Plowde and Thompson's normal glass. They had been tested N.P.L. about six months earlier and had shown a notab sluggish recovery of zero after being heated to about 100° C For the purposes of these experiments, all readings have been converted to the Celsius scale. One of the thermometers of Fig. 4 (67146/50) is of Jena 16''' glass and the others are of Tomey's normal glass, an English glass which has not been available since the early 1940's.

Vith all these thermometers, the first heating to 100°C s followed by rapid cooling (rate *A*). The thermometers Fig. 3 show a rather bigger depression than those of Fig. 4, : also a greater (though sluggish) recovery. The next ting to 100° C was followed by slow cooling (rate *C*) and depression occurred; indeed, the re-heating seems to have elerated somewhat the recovery from the previous depres- n. A further heating to 100° C followed by rapid cooling te *A*) produced a similar depression to that given by the t heating and, in some instances at any rate, there seems have been a slight acceleration of recovery when a subse- ent re-heating was followed by cooling at rate *B*. A second atment with rate *B* cooling which followed this produced carcely detectable depression or none at all; if it occurred, overy was rapid.

Fig. 5 shows the results obtained with two thermometers of well's normal glass, scaled up to 360° C and divided to ·2° C. These thermometers had large contraction chambers ontaining mercury equivalent to nearly 300° C on the scale, nd considerable difficulty was experienced through globules f mercury remaining in the chambers when the thermo- neters were cooled slowly. Thermometer 27390 could always e put in order by shaking (or sufficiently nearly so for a reliable reading to be made by making an allowance not exceeding 0·1° C for mercury left in the chamber), but thermometer 27391 had to be frozen down with solid carbon dioxide after each of the first four coolings. After the fifth cooling it was in a condition in which cooling in solid carbon dioxide could obviously do no good, and it was therefore not measured until it had been heated again and then cooled rapidly, after which no detached mercury was left behind.

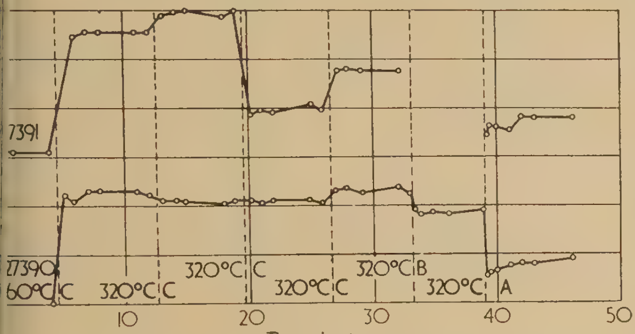

Fig. 5. Zero changes of thermometers of Powell's normal glass

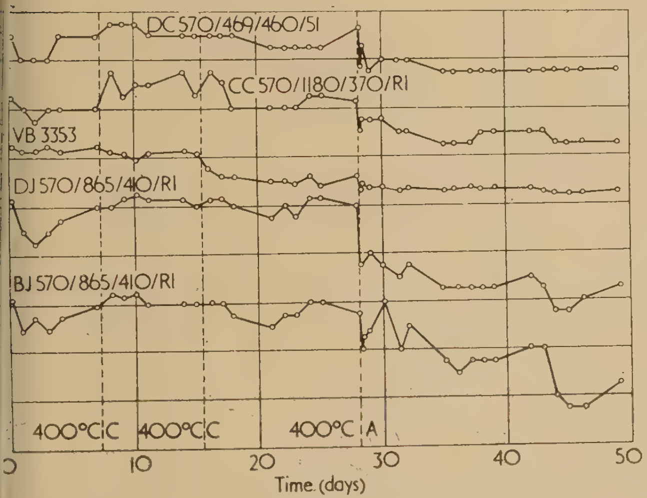

Fig. 6. Zero changes of thermometers of borosilicate glasses

The first heating of the thermometers was to 360° C, followed by slow cooling (rate *C*), and both thermometers, which had been at air temperature for several years, showed a rise of about 0·5° C. Heating was then restricted to 320° C, and after three heatings followed by slow cooling (rate *C*) thermometer 27390 showed no perceptible changes of zero, either temporary or permanent. Cooling at rate *B* produced a slight depression (about 0·1° C) while after the final heating to 320° C, rapid cooling led to a depression of about 0·25° C, the value normally to be expected with this type of glass. Recovery afterwards was very slow, only amounting to 0·06° C in seven days.

Thermometer 27391 shows erratic changes of zero after each of three heatings to 320° C followed by cooling at rate *C*, presumably because of the freezing with solid carbon dioxide. The thermometer remained untouched after the heating at 33 days until the heating at 39 days, and the difference between the readings at 32 days and 39 days shows a depression of 0·26° C, virtually the same as that given by thermometer 27390.

These experiments show that with normal glasses, cooling as slowly as rate *C* is sufficient to suppress completely the temporary zero depression, while rate *B* from 320° C is just too rapid to do so.

The experiments with borosilicate glasses are shown in Fig. 6. The thermometers whose numbers are prefixed by DC or CC are of Corning glass, while the remainder (prefixed VB, DJ and BJ) are of Jena 2954‴ glass. Thermometer VB3353 was divided to 0·2° C and the remainder to 1° C. The results show no measurable temporary depression when cooling from 400° C was carried out at rate *C*, but when cooling was at rate *A* we find depressions of 0·16, 0·13, 0·05, 0·25 and 0·15° C, the mean value being 0·15° C. In no case was there any appreciable recovery during 20 days following the heating.

COMPARISON OF RESULTS

The results of the experiments done at the N.P.L. with thermometers made of borosilicate glasses may be compared with those obtained at Amsterdam and recorded in Table 2. In neither experiment was any measurable recovery of zero noted during a period of several days, and the permanence of range test yielded, on the average, a rise of 0·16° C greater when cooling was slow than when it was rapid. This difference is almost exactly accounted for by the N.P.L. results, which show no depression of zero when cooling is slow, and a depression of about 0·15° C when cooling is rapid.

CONCLUSIONS

If the full zero rise caused by a "permanence of range" test is to be obtained, cooling of the thermometers should be slow. Cooling naturally in a furnace lagged so that cooling from 400 to 25° C occupied not less than 15 h (i.e. intermediate between rates *B* and *C* of Fig. 1) would be satisfactory. The time occupied from 100° C would then be about 8 h. Provided cooling is as slow as this, the reading of the zero after heating may be taken as soon as the thermometer has cooled down to about 15° C. Delay beyond this time does not affect the result.

It also follows from these experiments that in the ordinary use of a thermometer, when it is desired to observe the zero, the most reliable results would be obtained by cooling the thermometer slowly, rather than by natural cooling followed by a period for recovery at air temperature. This procedure also results in a saving of time, as the duration of cooling need never exceed about 15 h (e.g. overnight).

ACKNOWLEDGEMENTS

The experiments at the National Physical Laboratory were carried out as part of the research programme of t laboratory and are published by permission of t Director.

The experiments at the Koninklijke/Shell-Laboratoriu Amsterdam, were carried out in the course of the routi testing of various batches of thermometers, and are publish by permission of the management.

A method of flash synchronization for high-speed cinematography

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A description is given of the method used to synchronize a high-power stroboscope for use as the light source for high-speed cinematography. The essential requirements which had to be met were that the camera modifications should be kept to a minimum and that the synchronization should be effective over a speed range from 200 to 8000 frames/s.

INTRODUCTION

The laboratory study of non-repetitive phenomena by high-speed cinematography has been greatly encouraged since the advent of commercial cameras, of the rotating prism type, which are capable of speeds up to 10 000 frames/s while using full 16 mm format. However, these cameras have the disadvantage that the exposure time for individual frames is related to the framing rate by the action of the prism shutter; so that even with the maximum speeds available it may not be possible to arrest the motion of objects moving with high angular velocity relative to the optical axis. This limitation often prevents a detailed frame by frame analysis from being made, with the result that it may be necessary to supplement the good time resolution of the high-speed cine camera with the space resolution obtained from still photography using micro-second flash or spark illumination. Nevertheless, it is possible to combine the advantages of both techniques by synchronizing a short-duration flash discharge tube to be used as the light source for high-speed cinematography, e.g. the specially designed Acmade camera and stroboscope system.(1)

This paper describes a method that has been devised to enable a high-power high-speed stroboscope (by Ernest Turner Electrical Instruments Ltd.) to be synchronized with a 16 mm Fastax camera (by Wollensak Optical Co.) over the full speed range of the latter (i.e. up to 8000 frames/s); although the technique should also be suitable for application to any other camera of similar basic design. An important consideration which influenced the choice of synchronizing mechanism, was that the camera alterations should be kept to a minimum and that these should not affect the operation under normal conditions of steady illumination. Therefore, the cameras are not restricted to use with the stroboscope alone.

GENERAL DESCRIPTION

The design and early development of the power stroboscope and high-pressure xenon flash discharge tube have been described in detail elsewhere.(2) Later improvements to this equipment have enabled the maximum frequency to be raised from 4000 to 8000 flashes/s, each with an energy of 2 J and an effective duration of approximately 2 μs. At this energy level, it is necessary to limit the maximum number of consecutive flashes to about 2000 to prevent overheating th quartz discharge tube.

The design principles of the rotating-prism type of high speed cine camera have also been described elsewhere.(The camera used for this work had a capacity of 100 ft standard 16 mm film and was capable of speeds up 8000 frames/s using the normal equipment for pre-setting th voltage and duration of the electrical supply to the camer driving motors. A characteristic of this system is that th camera speed increases throughout each run, although th maximum acceleration takes place during the first 20 c 30 ft; which meant that flash synchronization had to b effective on every frame. Moreover, the very wide usab speed range of the camera (over 20 : 1) demanded that a time delay in the synchronizing device should be kept to minimum, or some adjustment must be provided. Thes requirements, coupled with the need to avoid structur alterations to the camera as far as possible, largely dictate the approach to the problem.

Three possible synchronizing techniques were originall considered, i.e.:

(1) By means of an electro-optical system similar to tha used in the Acmade camera. In this method the norma camera rotating prism is used to interrupt a beam of colli mated light directed on to a photocell; however considerabl alterations to the camera would be necessary.

(2) Electro-magnetic triggering from a small magnetic slu attached to the prism housing.

(3) By the use of an electro-magnetic reluctance pick-u placed adjacent to the teeth on the film driving sprocke (there being one sprocket tooth per frame with standar 16 mm film).

It was decided to utilize the last of these techniques, sinc this appeared to involve the least amount of alteration t the camera. Preliminary tests were, therefore, carried out t investigate the suitability and effectiveness of the method the success of which resulted in a pick-up being permanentl installed in the camera, as shown on Fig. 1. The pick-u mounting block was designed to allow the clearance over th sprocket teeth to be adjusted, and to enable the pick-up t be positioned to give the correct phase relationship for the power stroboscope, which required a positive going pulse o at least 10 V and having a sharply rising leading edge fo precise synchronization from an external source. The reluctance pick-up itself consists of a small solenoid with a extended pole piece ground to the approximate profile of the ocket teeth; while at the other end of the solenoid a ular permanent magnet provides the polarizing field. en correctly adjusted, the flash discharge should take ce when the faces of the rotating optical compensating ck are perpendicular to the optical axis, the pick-up uld also be positioned to give the minimum working arance between the pole piece and sprocket teeth.

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* Ernest Turner Electrical Instruments Ltd., High Wycombe, Bucks.

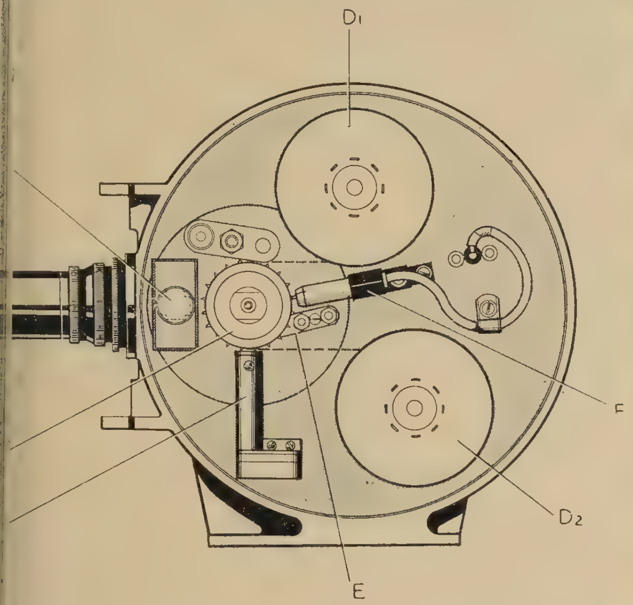

Fig. 1. Camera used with reluctance pick-up installed

A, rotating optical compensating prism; *B*, sprocket wheel; *C*, timing light; D_1, D_2, film spools; *E*, stripper plate; *F*, magnetic reluctance pick-up.

Electrical connexion between the reluctance pick-up and e external triggering circuit of the power stroboscope is ade through a special pulse amplifier, a schematic circuit agram for which is given as Fig. 2. As each sprocket tooth asses the pick-up pole piece, the pulse generated is transnitted by co-axial cable to the high-ratio input transformer f the pulse amplifier, which is carefully screened from xternal magnetic fields. After passing through a wide band mplifier, the pulse is then applied to a Schmidt trigger ircuit the output of which is differentiated, shaped and mplified to produce a very narrow positive going pulse of hort rise time and of approximately 50 V amplitude irrepective of the original input amplitude from the pick-up. This is necessitated by the fact that the input transformer econdary voltage can vary from a few millivolts at the owest camera operating speed, up to several hundred nillivolts at the maximum framing rate.

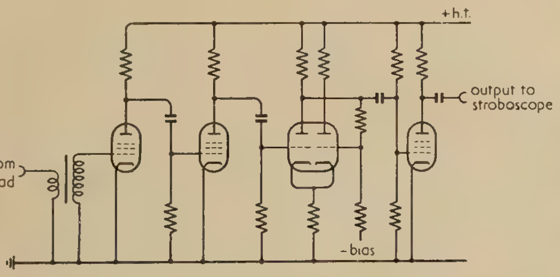

Fig. 2. Schematic circuit of camera pulse amplifier

The accuracy of synchronization over the operating range from 200 to 8000 frames/s was found to be well within the permissible change of angular position of the rotating prism; therefore, it is unnecessary to have to re-position the pick-up according to the particular speed range. A simple method of checking the effectiveness of synchronization, is to view the camera prism by illumination from the stroboscope itself (or a similar low-power unit). By this means, adjustments of the phase relationship can readily be made without recourse to photographic methods except as a final check.

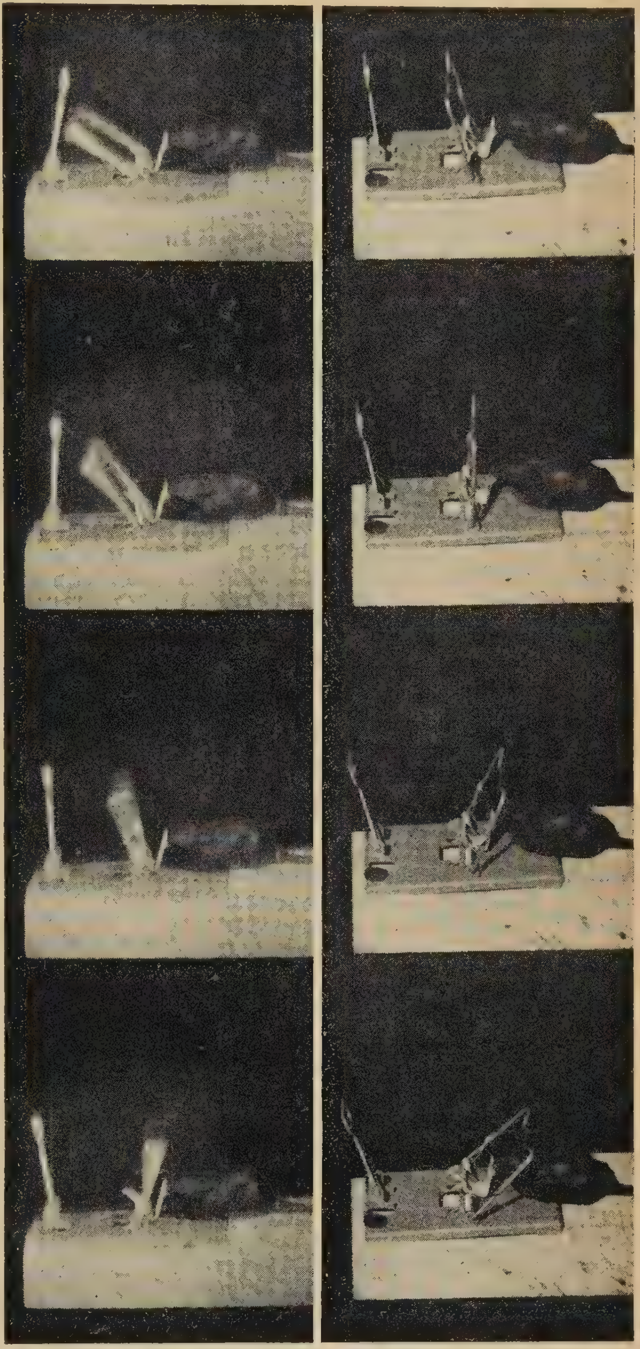

Fig. 3. (*a*) Continuous illumination. (*b*) Stroboscopic illumination (camera speed approximately 1500 frames/s)

OPERATION

Basic camera operation is unaffected by the addition of the synchronized flash equipment, the framing rate and running time being controlled by the standard Goose camera control unit (by Industrial Timer Corporation). This control equipment contains two adjustable time switches, the first of which is used to limit the running time of the camera motors, and the second is intended as an event timer which may be set independently of the camera timer. For use with synchronized flash illumination, this event timer is used to start the stroboscope through the "remote-start" control provided, and should be set to operate after a sufficient time interval to allow approximately 30 ft of film to pass through the camera. By this means, it is possible to make the best use of the limited number of consecutive flashes (about 2000) imposed by considerations of flash tube life. The actual running time of the stroboscope is governed by a process timer which is adjusted in conjunction with the estimated camera speed to limit the total number of flashes. In practice, very little inconvenience is experienced by this limitation, since the wasted portion of the total available film mainly consists of the period of rapid camera acceleration which is of least value for analysis purposes.

The complete equipment for synchronized flash cinematography comprises the camera, camera electrical control equipment, camera timing light generator, pick-up pulse amplifier unit, power stroboscope and short duration flash discharge tube.

APPLICATIONS

The adaptation of the Fastax camera for synchronized flash cinematography was originally undertaken to assist with the study of liquid atomization and the break-up of liquid sheets, both of which are subjects that demand the good time and space resolution that can be obtained with this technique. However, synchronized flash cinematography is equally suitable for similar laboratory subjects which are non-luminous and cover a comparatively small field of view (the light output from the discharge tube is sufficient to provide adequate illumination over an area of approximately one square metre, if modern high-speed films are used).

It has been found that there is an appreciable gain picture definition and quality when using synchronized fla illumination with the rotating prism type of high-spe camera, even where the subject exhibits little moveme This can be attributed to the effective frame exposure occu ring when the compensating prism is at right angles to t optical axis, thus minimizing distortion due to imperfe compensation and preventing unevenness of exposure fro the effects of scanning. Fig. 3 shows examples taken from demonstration film to show the difference between strob scopic and continuous illumination, and illustrates t improvement to be found in both stationary and movi parts of the subject. Apart from the method of illuminatio other experimental details were the same for both film i.e. camera distance and framing rate, the film material an the lens aperture.

A further incidental advantage to be gained from the u of flash illumination results from the very considerab reduction in subject heating compared with the equivale intensity of continuous light.

For certain applications the two additional benefits improved definition and reduced subject heating, could pro to be more important reasons for using synchronized flas illumination than the more obvious advantage of reduce exposure times on individual frames.

ACKNOWLEDGEMENTS

The pick-up pulse amplifier equipment was developed b Ernest Turner Electrical Instruments Ltd. The authors wis to acknowledge the help and co-operation of Dr. W. Beakle Mr. C. S. Brasier and Mr. E. C. Kinch, Royal Aircra Establishment, Westcott.

REFERENCES

(1) Chesterman, W. D., and Peck, G. T. *Photogr. J.*, **92** p. 133 (1952).

(2) Chesterman, W. D., Glegg, D. R., Peck, G. T., an Meadowcroft, A. J. *J. Instn Elect. Engrs*, **98**, p. 62 (1951).

(3) Waddell, J. H. *High Speed Photography*, *Vol.* 2, p. 7 (New York: Society of Motion Picture Engineers, 1949

A vibration pick-up which does not load the system being examine

By S. K. Rushforth and A. Selwood, Ph.D., Grad. Inst.P., Wind Tunnel Department, Bristol Aircraft Ltd., Bristol

[*Paper first received* 18 *February, and in final form* 28 *March*, 1958]

The present device measures the amplitude, and indicates the phase of vibration of a structure without touching or loading it in any way. The transducer may be positioned anywhere adjacent to the surface of the structure so as to measure its amplitude of vibration at any given point. The apparatus is only suitable for the measurement of continuous simple harmonic oscillations such as appear in resonance testing.

A moving-coil vibrator is held close to the structure and is electrically driven so that the vibrator oscillates in sympathy with the structure. This sympathy of movement is detected by measuring the electrical capacitance between two plates, one formed by the structure itself, and one mounted at the tip of the vibrator shaft. The amplitude and phase of the current which drives the vibrator are adjusted until this capacitance becomes constant. The vibrator then moves with the same amplitude and phase as the structure and any type of vibration amplitude pick-up may be permanently fixed to the vibrator shaft. Whatever mechanical power is absorbed by this measuring pick-up comes from the supply to the vibrator and not from the structure itself.

In the present apparatus, used for resonance testing a small wind-tunnel model, vibration amplitudes up to 0·030 in. may be measured with good linearity and reproducibility, with a resolution of about 0·0001 in. It is essential that the structure under examination be metallic, or, if not, covered with an electrically conducting layer.

It is convenient to measure vibration amplitude with an electrical pick-up which is calibrated before use. There are many types of pick-up which may be used, ranging from capacitance and moving-coil devices to differential transformers and photo-electric pick-ups. Calibration methods are usually simple in principle, involving some optical effect h as the use of microscopes, optical levers, Foppl's ngles or interference fringes.* In general, vibration k-ups suffer from one of two limitations. They either put nechanical load upon the structure under examination or y cannot be moved from one point to another without nge of sensitivity. This last is particularly true of capaci- ce and photo-electric transducers.

The apparatus which is to be described was made to asure vibration mode shapes on a small wind tunnel tail- ne model. The tailplane structure weighed only 60 g and was required to measure its amplitude of vibration at about o dozen points over its surface. These two requirements ade it impossible to use any existing device and led to the evelopment of the present apparatus. The principle of the ethod is illustrated in Fig. 1 which is a block diagram of the hole apparatus used to excite a structure into vibration, and easure the mode shape of the vibrating structure. It is nvenient to excite the structure by means of a small ermanent magnet fixed to it and moving with one pole in e gap of a stationary electromagnet. The electromagnet is pplied from a power amplifier and a master oscillator.

The pick-up consists basically of a vibration generator hich is driven from the master oscillator *via* a separate ower amplifier. The amplitude and phase of the supply to e vibration generator may be varied. A small electrode is ttached to the tip of the shaft of the vibration generator and hen this is held close to the structure a capacitor is formed y the electrode and the structure. (The structure is earthed.) his capacitance is measured by a proximity meter (by ielden Electronics Ltd.) whose output is displayed on an scilloscope. If the phase and amplitude controls in the upply to the vibrator are adjusted it is possible to make the ibrator move exactly in sympathy with the structure and hus make the electrical capacitance between the plates on he vibrator and on the structure constant. This is done by djusting the amplitude and phase controls in the vibrator upply until the oscilloscope signal is minimized. The mplitude of vibration of the pick-up shaft may then be neasured by any conventional method. In the present pparatus a second moving-coil device is used. Whatever nechanical power is taken by this last pick-up comes from the vibrator power supply and not from the vibrating structure.

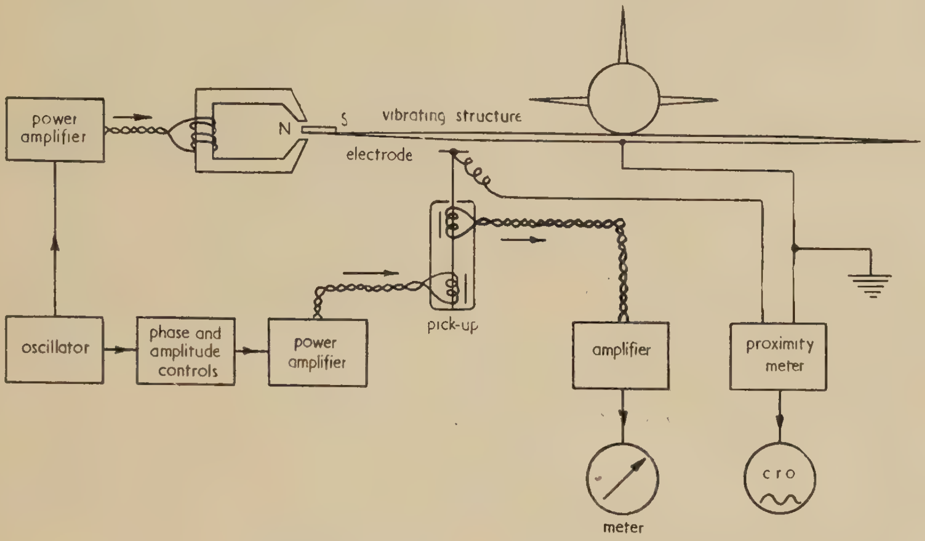

Fig. 1. Block diagram of the complete vibration apparatus

CONSTRUCTION

The pick-up is a modified vibration generator (type V47, by Goodmans Industries), which has a second moving coil pick-up added to it, as is shown schematically in Fig. 2. (In the actual pick-up used here, a d.c. electromagnet was used in the measuring transducer because no suitable permanent magnet was to hand.) The electrode fixed to the tip of the shaft consists of a disk of brass shim, 1 cm in diameter. This plate has a small pin-point at its centre which is useful to position the pick-up in relation to the structure under examination.

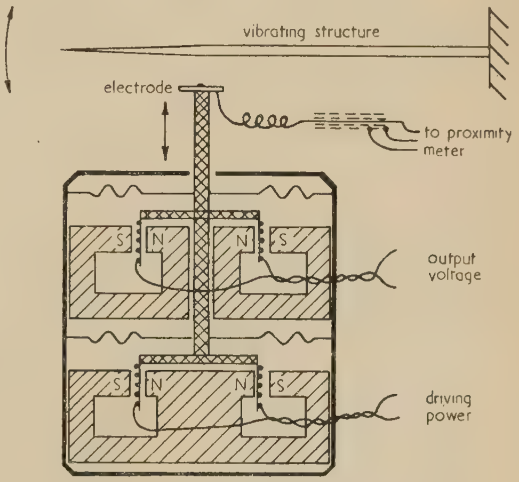

Fig. 2. Schematic diagram of pick-up

The output from the measuring pick-up is only a few millivolts. This is amplified in a two-stage linear amplifier. The amplifier output is rectified and displayed on a moving coil meter. A step-resistor is included in the gain control of this amplifier to give various ranges of meter sensitivity. The circuit of this amplifier is shown in Fig. 3.

The circuit shown in Fig. 4 enables the phase of the supply taken from the master oscillator, to be varied through 360° and the amplitude varied from zero to maximum. The resulting signal is amplified to a power level of a few watts (maximum) and is then applied to the driving coil of the vibration generator. In the construction of this part of the apparatus it was found necessary to keep 50 c/s hum at a minimum and to ensure that the amplifiers introduced no harmonic distortion.

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* Foster, K. C. *Electronic Engng*, **29**, p. 468 (1957).

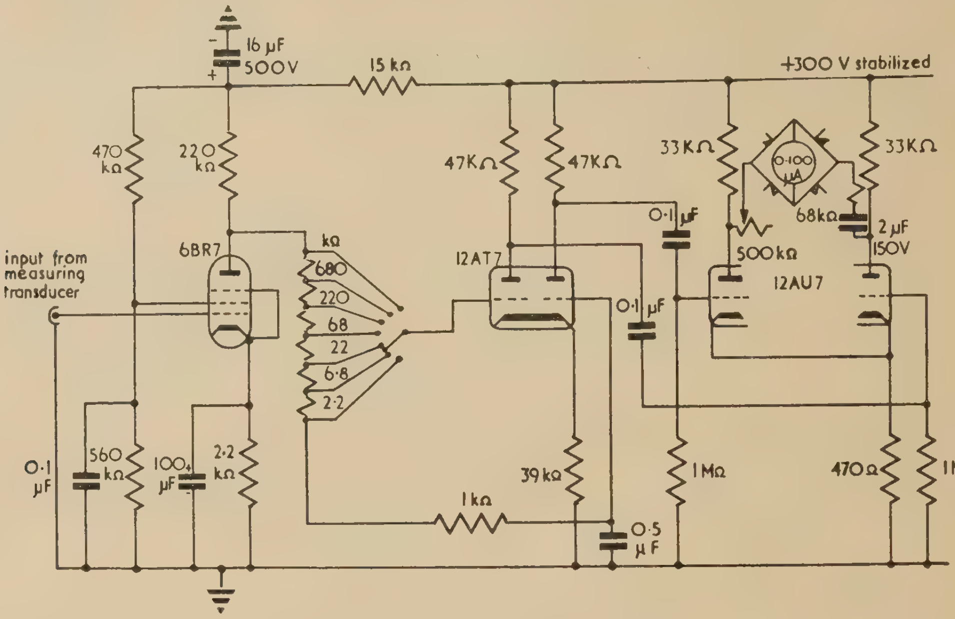
16 μF
500V
15 kΩ
+300 V stabilized
470 kΩ
220 kΩ
47KΩ
47KΩ
33KΩ
33KΩ
0-100 μA
0·1 μF
68kΩ
2 μF
150V
500kΩ
12AU7
input from measuring transducer
6BR7
kΩ
680
220
68
22
6·8
2·2
12AT7
0·1 μF
0·1 μF
560 kΩ
100 μF
2·2 kΩ
39 kΩ
1 kΩ
0·5 μF
1MΩ
470Ω
1MΩ

Fig. 3. Measuring transducer amplifier

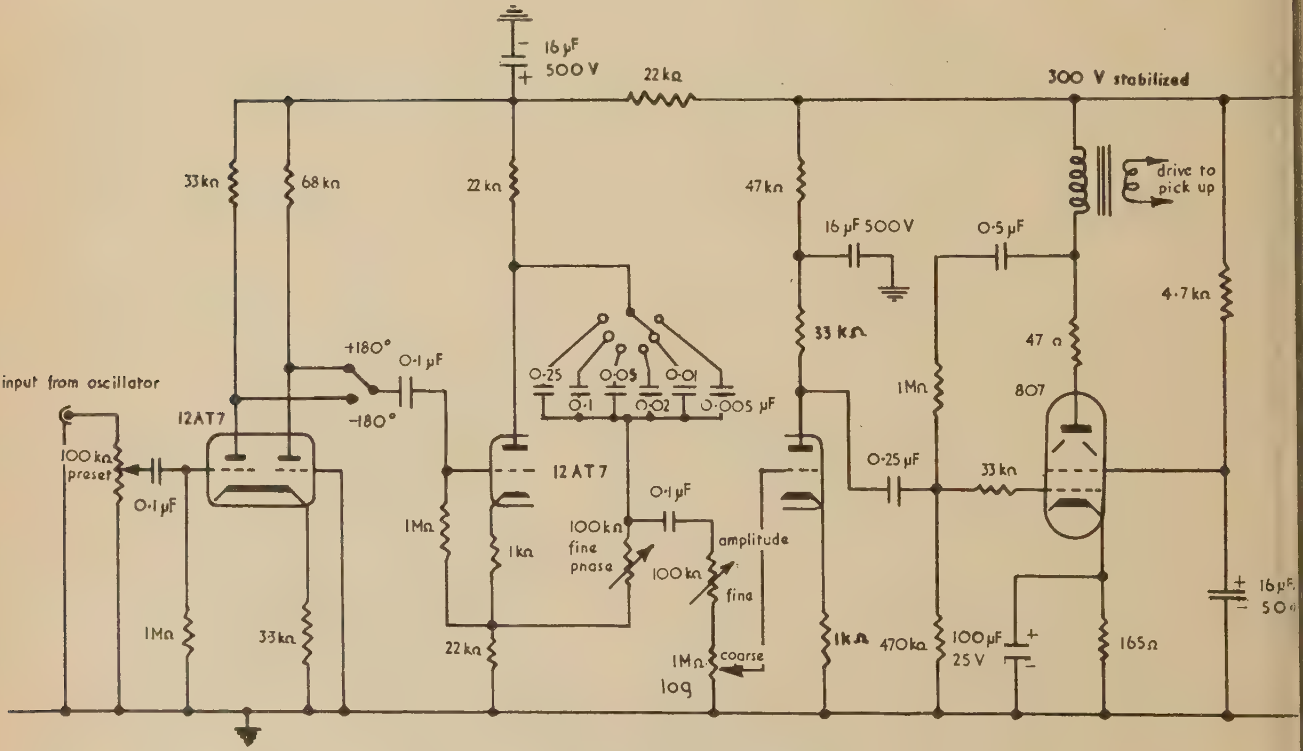
16 μF
500 V
22 kΩ
300 V stabilized
33 kΩ
68 kΩ
22 kΩ
47 kΩ
drive to pick up
16 μF 500 V
0·5 μF
4·7 kΩ
33 kΩ
47 Ω
+180°
0·1 μF
-180°
0·25
0·1
0·05
0·02
0·01
0·005 μF
1MΩ
807
input from oscillator
12AT7
100 kΩ preset
0·1 μF
12 AT 7
0·25 μF
33 kΩ
1MΩ
1 kΩ
100 kΩ fine phase
0·1 μF
amplitude
100 kΩ fine
1MΩ log
coarse
1MΩ
33 kΩ
22 kΩ
1 kΩ
470 kΩ
100 μF 25 V
165 Ω
16 μF 50

Fig. 4. Phase-shifting power amplifier

CAPACITANCE MEASURING APPARATUS

A standard proximity meter (by Fielden Electronics Lt is used to measure the capacitance between the electrode the tip of the pick-up shaft and the earthed vibrating structu No modifications are necessary but the double screened cab which is supplied with the apparatus must be continued near to the electrode as possible. The output of the proximi meter is displayed on an oscilloscope. In use, the pick-up ought up to the vibrating structure until the electrode is out $\frac{1}{16}$ in. away when judged by eye. This separation is t critical, resulting in first-order changes of Fielden nsitivity only.

All-metal structure are, of course, the only ones which may examined directly; when insulating structures are being sted it is necessary to coat them with earthed aluminium foil.

CALIBRATION

For very many purposes an absolute calibration is not quired and this is true in the present application. The easuring pick-up used here gives an output which is directly oportional to frequency. This is useful because low equency vibrations have larger amplitudes than do high equency vibrations of the same power. However, the vice has been calibrated to test stability and linearity. The ethod of calibration employed involves vibrating a section coarse diffraction grating perpendicular to the rulings and ewing the resulting pattern under a microscope. The lines the grating are seen doubled because they appear to be nsest at the extremes of the motion where the speed is ast. When the pattern of rulings disappears then the bration amplitude is

$$A = \frac{(2n+1)}{2}P$$

here P is the pitch of the grating and n is an integer. When e pattern of the grating appears distinct, the vibration nplitude is

$$A = n.P$$

sing a section of Dufaycolor film reseau which has a rinted grating of pitch 0·002 in., orders of reinforcement p to the tenth may be observed, thus giving increments f 0·001 in. up to 0·02 in. Other gratings of finer pitch may be used to calibrate the pick-up on more sensitive ranges. Fig. 5 is a calibration for the pick-up made at a frequency of 245 c/s and with the output meter set at a middle range of sensitivity.

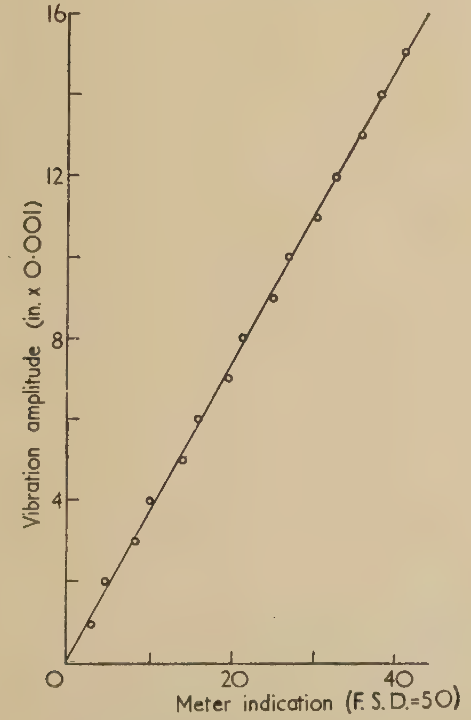

Fig. 5. Calibration at 245 c/s—middle range of sensitivity

TYPICAL EXPERIMENT IN WHICH THE MODE SHAPE OF A VIBRATING BEAM IS MEASURED

A steel bar $\frac{1}{2} \times \frac{1}{2} \times 26$ in. was clamped at one end and set into oscillation by means of a small permanent magnet attached to the free end of the bar. Measurements of the vibration amplitude were made at intervals along the length of the bar. The resulting mode shapes for the fundamental and first two overtone modes which appear when the bar is excited at the appropriate frequencies are shown in Fig. 6.

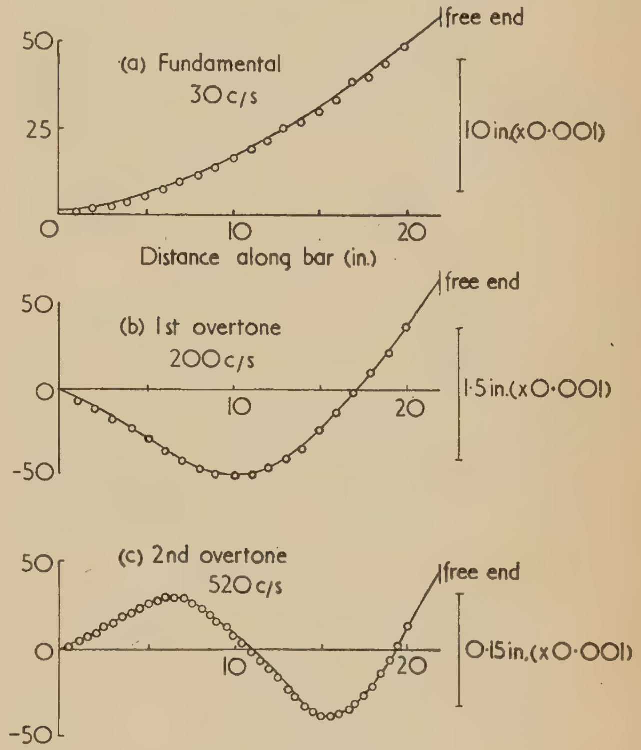

Fig. 6. Mode shapes

In this experiment the transducer was mounted in a heavy retort stand. The weight of the transducer itself is sufficient to prevent unwanted movement of the body of the transducer.

In an experiment of this kind it is easy to restrict vibration measurements to those of a particular overtone because the other harmonics may be discriminated against when the oscilloscope screen is viewed. In the measurements made for Fig. 6(c), for example, the bar was vibrating at its fundamental frequency (due to spurious excitation) with amplitudes ten times greater than those of the 2nd overtone, yet this could easily be discounted. Very few other vibration measuring techniques possess this advantage.

DAMPING MEASUREMENTS

Since the output of the measuring pick-up always exhibits the same phase-relationship with respect to the vibrating structure, the apparatus may be used in conjunction with a phasemeter. This enables structural damping, and air damping measurements to be made.

A permeameter controller for magnetic measurements

By M. J. Swan, National Physical Laboratory, Teddington, Middlesex

[*Paper received* 10 *January*, 1958]

Determinations of the magnetic properties of materials by the ballistic method often involves complicated switching of the magnetizing currents. A semi-automatic controller has been built which carries out the switching operations and ensures the material is maintained in a cyclic magnetic state. The N.P.L. permeameter is also briefly described.

INTRODUCTION

The several types of precision permeameter used in magnetic measurements(1) commonly have more than one magnetizing winding, and the control of the currents during the delineation of, say, a hysteresis loop generally demands a complicated series of switching operations. At the National Physical Laboratory, a permeameter having two windings is used and, in order to simplify and speed the measurements, an automatic switching apparatus has been developed which considerably reduces the amount of time and effort previously required in the operation of manual switches. A description of this apparatus is given below; it has features which may be of general use where the cyclical switching of currents is required.

THE N.P.L. PERMEAMETER

The N.P.L. permeameter has been described in detail elsewhere(2) and only a brief account is necessary. The sample to be tested is in rod or bar form, the most convenient dimensions being 25 cm long by about 4 cm^2 in cross-section. It is inserted in a bobbin which carries a uniform main winding and a smaller compensating winding which is in two equal sections concentrated at the ends; the overall length of the bobbin is about 17 cm and the magnetic circuit is completed by two massive U-shaped yokes of laminated silicon-iron (Fig. 1). Soft iron pole-pieces are used to accommodate the shape of the sample and distribute the flux across the yoke ends.

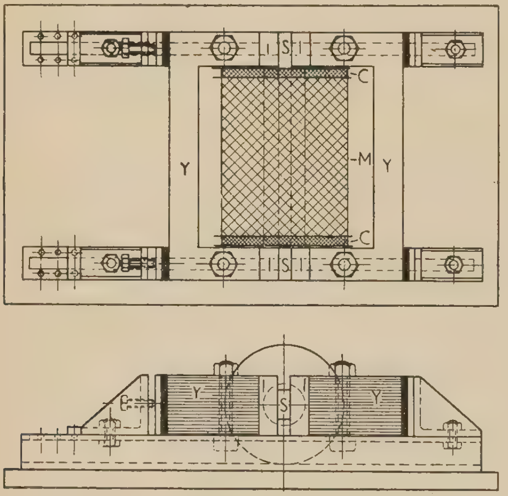

Fig. 1. The N.P.L. permeameter

C, compensating winding; *I*, soft iron pole-pieces; *M*, main magnetizing winding; *S*, sample; *Y*, laminated iron yokes.

Measurements are made by changing the magnetizing currents and noting the resultant change in field *H*, and flux density *B*, indicated by ballistic galvanometers connected to secondary circuits in the permeameter. These secondar circuits consist, in the case of *H*, of coils on glass forme strapped to the sample and axially parallel with it; the coil is wound around the sample: both sets of coils exten over about 8 cm in the middle of the sample. This centr 8 cm is the tested length of the sample and it is essential tha over it uniform conditions of magnetization exist. Th compensating magnetizing coils, mentioned earlier, provid a magnetomotive force to overcome the reluctance at th joints between sample and yoke and so suppress leakage flu in the test length. The method of detecting uniformity of is to have a winding on the specimen, formed of two par each having the same number of turns, one part concentrate at the centre, and the other equally divided between the tw ends of the test length; one part is wound in the opposit one on reversing the flux will exactly neutralize that in th other when the flux is uniform. The method of operation to set the current in the main winding to an appropriate valu and adjust the compensating winding current until the abov condition is obtained. The switching required to achiev this is most elaborate when a hysteresis loop is required an attention will therefore be directed to this measurement.

HYSTERESIS LOOPS

Fig. 2 shows a hysteresis loop. Points 1 and 7 are th tips of the loop and are fixed for a given test; all other point are determined by differences from these points. Table indicates the direction of the current in the main and compensating windings for two other subsidiary fixed point 3 and 5 and for typical points between them.

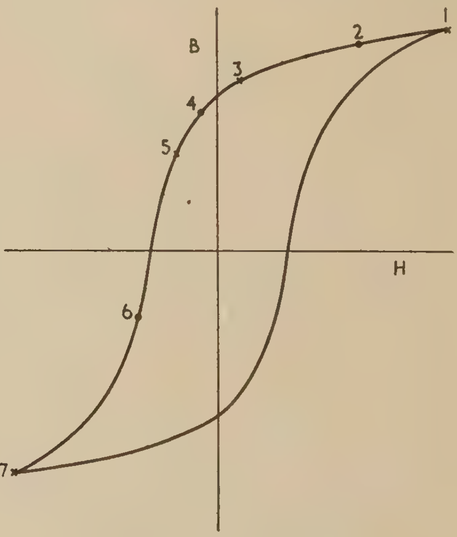

Fig. 2. Hysteresis loop

Measurements are first made between 1 and 7 to fix these points by their value of *H* for a given value of *B* or *vic* *rsa.* Point 3 is then investigated; this is commonly used as subsidiary fixed point, being that point where no current is owing in the main winding; readings are taken from 1 to 3 nd from 3 to 7 to determine its position. The loop above 3 then completed by taking readings on the changes from to 2 and from 2 to 3, varying the position of 2 by appro-iate changes in the main and compensating currents; adings are then taken on the changes from 3 to 4 and so n until the loop is completed.

Table 1. *Main and compensating circuit currents*

Loop point	1	2	3	4	5	6	7
Main current	Max +	+	0	−	−	−	Max −
Compensating current	Max +	+	+	+	0	−	Max −

Delineating loops with values of B_{max} not exceeding, say, 0 000 G, usually involves taking as few as fifteen points, ut at higher values a large number of observations must e taken if the area of the loop is to be obtained accurately.(3) hus the mechanical effort alone of switching can be tedious, nd added to this is the necessity of ensuring that one always nakes changes in the sequence 1, 2, 3 . . . 7, 1 in order to eep the material in a cyclic magnetic state. Until recently drum controller designed by Webb and Ford(4) which uaranteed this cyclic continuity was used, but it was found hat the contact resistance of this switch was variable to a light extent; this may become important when the magnetiz-ng current is high and the total circuit resistance con-equently low.

A new controller was therefore constructed embodying the uality of cyclic operation with those of heavy current apacity and simple manipulative operation.

THE NEW PERMEAMETER CONTROLLER

The circuit diagram for the main (*M*) and compensating C) magnetizing windings of the permeameter is shown in Fig. 3. All the switches indicated are mercury in glass, relay operated; these were adopted as being capable of dealing with the heavy currents and high voltages associated with the permeameter and other magnetic testing equipment of large inductance. Cyclic operation of these switches is effected by a uniselector which controls them *via* Post Office relays; this uniselector may be arrested to give any of seven circuit conditions, corresponding to the seven points indicated on the hysteresis loop of Fig. 2, by push buttons numbered 1 to 7. A further push button, 8, allows the uniselector to operate continuously, 1, 2, 3 . . . 7, 1, carrying the sample round continuous cycles of magnetization; this is a useful facility when demagnetization has to be carried out.

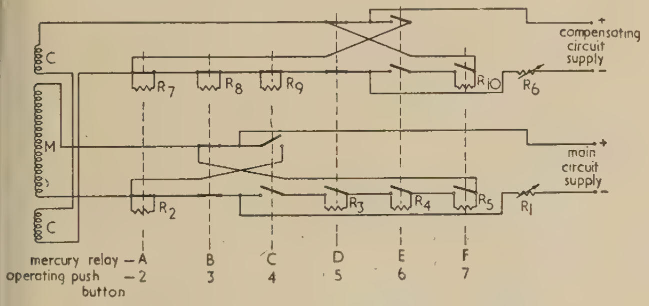

Fig. 3. Permeameter supply circuits

A disadvantage of the mercury-in-glass switch is the difficulty experienced in arranging two or more to operate simultaneously. Simultaneous operation is necessary between the main and compensating currents at each of the seven points, and this is accomplished by mounting the switches to be synchronized on a common relay platform and adjusting their supports until the mercury pools part simultaneously at a slow rate of tilt. An interval timer shows that the method is satisfactory for normal speeds of operation and that the switches are repetitive. It is also difficult to ensure that the switches *B* and *C*, in the main circuit (Fig. 3), and *D* and *E*, in the compensating circuit, operate in the correct sequence when cycling. This is essential because reversals of current take place, and the circuits must open in one direction before they close in the other in order not to short circuit the supply; at the same time too long an interval between break and make would result in two impulses in the secondary circuit, the second of which might not be fully integrated by the ballistic galvanometer. Both mechanical linkage and the use of slugged Post Office relays were tried unsuccessfully; finally, since the mercury switches themselves were consistent in operation, as demonstrated by the simultaneity tests mentioned above, the use of a small mercury switch as an electrical interlock mounted on a switch platform to prevent subsequent relays operating was adopted; this makes the behaviour of the switches so consistent that intervals between their operation of 50 ± 20 ms is obtained. The obvious solution to the above problem, that of using mercury change-over switches, was not adopted because manufacturers were unable at the time the equipment was built to guarantee the break before make on heavy duty switches.

As may be seen from Fig. 3 and Table 2, the function of each bank of mercury switches is to insert resistance in stages in the magnetizing circuits, eventually opening them, and then to reduce the resistance in the reversed direction in stages until full reversed current flows with the operation of relay *F* (push button 7 and loop tip). As the Post Office relays operate the mercury switch relays *A*, *B*, *C* . . . to *F*, under the control of the uniselector, each energizes itself so that it holds on while the uniselector moves on to its next position; they are all released when the uniselector returns to its first position. Delay devices, variable between 1 and

Table 2. *Operations performed by mercury switches*

Push button	*Mercury switch relays operated*	*Main magnetizing current*	*Compensating magnetizing current*	*Point on loop*
1	None	Set by R_1	Set by R_6	1
2	A	Reduced by inserting R_2	Reduced by inserting R_7	2
3	B	Reduced to zero	Further reduced by adding R_8	3
4	C	Reversed and reduced by R_3, R_4 and R_5	Still further reduced by adding R_9	4
5	D	Reversed and reduced by R_4 and R_5	Reduced to zero	5
6	E	Reversed and reduced by R_5	Reversed and reduced by R_{10}	6
7	F	Reversed	Reversed	7
8	All in sequence			cycle

2 s are incorporated in the circuits of relays *A* and *F* to ensure that the changes from push button positions 1 to 2 and 7 to 1 are not rapid. The reason for the delays is to enable the flux in the sample to attain its full value at the maximum value of *H*; the time necessary for this depends on the section and nature of the material, but 1 to 2 s is sufficient for most samples—unusual samples can be arrested at the tip points for longer periods by using the tip point buttons. The full sequence of operations is shown in Table 2.

PERMEABILITY MEASUREMENTS

For permeability measurements only the tip buttons 1 and 7 are used, the material being cycled a few times at each new point before observations are taken. For tests where no compensation is necessary (roughly above $H = 15$ oersteds) switches *A*, *D*, *E* and *F* are short circuited so that the time for the reversal is only that required for the operation of *B* and *C*. When compensation is used *A* and *F* are shorted in each circuit and the resistors across *B* in the compensating circuit and *E* in the main circuit removed; in this condition breaks and makes in the main and compensating circuits are synchronized.

The controller is also used to operate an electromagnet in which permanent magnet materials are tested. Since thi apparatus is highly inductive, voltages of over 1000 V ma be developed across the opening switches; even under thes exacting conditions the behaviour of the controller satisfactory.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of hi colleagues in preparing this paper, and in particular M C. E. Webb who also helped with advice in the design of th apparatus. This paper is published by permission of th Director, National Physical Laboratory, the work bein part of the research programme of the Laboratory.

REFERENCES

(1) Vigoureux, P., and Webb, C. E. *Electric and Magneti Measurements* (Blackie and Son Ltd., 1936).

(2) Webb, C. E., and Ford, L. H. *J. Instn Elect. Engrs*, 67 p. 1302 (1929).

(3) Webb, C. E., and Ford, L. H. *J. Instn Elect. Engrs*, 64 p. 409 (1926).

(4) Webb, C. E., and Ford, L. H. *J. Instn Elect. Engrs*, 68 p. 1018 (1930).

A piezo-electric pressure bar gauge

By D. H. Edwards, Ph.D., Department of Physics, University College of Wales, Aberystwyth

[*Paper first received* 14 *February, and in final form* 23 *April*, 1958]

A pressure bar gauge is described in which the average stress over the cross-section of the bar is measured by means of an X-cut quartz disk. Bars of duralumin and lead are employed since the acoustic impedances of these materials closely match the value appropriate to longitudinal thickness vibrations in the quartz. The design of a gauge housing, suitable for mounting in the wall of an explosion or shock tube, is discussed.

A large proportion of the measuring devices which have been designed for the recording of rapidly varying pressures employ some crystalline material, which exhibits the piezo-electric effect, as their sensitive element. The choice of crystal is governed largely by the type of pressure for which the gauge is intended and the design of the gauge. When considerations of mechanical strength and thermal stability override those of sensitivity preference is generally given to quartz and tourmaline. A large number of gauge designs employing these crystals, which have been developed for a variety of applications, is described in the literature.

A difficulty which is encountered with every type of pressure gauge which is subjected to pressure which varies rapidly with time, arises from the presence of vibrations in the gauge output due to excitation of the natural frequencies of the sensitive element together with vibrations which originate in the gauge housing which may be transmitted to the sensitive element. The presence of a certain amount of "ringing" in the gauge is inevitable and the objective in gauge design is to minimize this effect without undue sacrifice of the high-frequency response of the gauge. Therefore a solution of this problem is generally a compromise. In piezo-electric gauges the tendency of the crystal to oscillate in its natural modes may be reduced by providing suitable damping of the crystal, e.g. by loading the crystal with electrodes or, in the case of hydrostatically sensitive crystals, such as tourmaline, by immersing the crystal in oil.$^{(1)}$ Again, housing vibrations which may be transmitted to the crystal may be made to cancel by using two or more crystals mounte in a suitable manner.

THE PRESSURE BAR METHOD

When the pressure changes are rapid, like those encountered in gaseous detonation and shock waves, the presence o gauge vibrations usually makes it extremely difficult to obtain the true pressure variations in the wave; the problem may be complicated further if high frequency pressure oscillations occur in the wave being measured. For this reason a good deal of attention has been devoted in this laboratory to the development of the pressure bar method for the measurement of both static and reflexion pressures in gaseous detonation waves. A detailed theoretical treatment of the propagation of stress pulses in cylindrical bars is given by Davies$^{(2)}$ who has also devised and investigated several methods of recording the stress variations. The method showed considerable promise and some of the results obtained in preliminary investigations are described by Edwards,$^{(3)}$ Davies, Edwards and Thomas,$^{(4)}$ and Thomas.$^{(5)}$ The main advantage of the method over other types of gauge lies in the fact that the bar is essentially an aperiodic device and even when a certain amount of dispersion of a stress pulse propagating in the bar occurs, its effects can be identified and accounted for in the interpretation of the record. Its principal disadvantage in the present application, which involves pressures in the range 10–100 atm, is its comparative insensitivity when a parallel-plate capacitor gauge is employed, in the usual nner, to measure the displacement of the free “measuring-l” of the bar.

THE DURALUMIN BAR GAUGE

n order to overcome this disadvantage an alternative thod of measuring the average stress over the cross-section the bar was investigated. In essence the method employs X-cut circular quartz disk to measure the stress over the ss-section of a duralumin bar of the same diameter. If quartz disk is backed by a second, similar duralumin bar, n a stress pulse travelling in the first bar will be transmitted ough the quartz into the second bar. Furthermore, no lexion of the stress pulses will occur at the quartz-duralumin erface provided the acoustic impedance, ρc_0 [where ρ is density of the material of the bar, $c_0 = (E/\rho)^{\frac{1}{2}}$, and E is ung's modulus] of the duralumin is matched to that propriate to the thickness vibrations in the quartz disk. e measured value of ρc_0 for the duralumin used in the sent work was found to be $1\cdot42 \times 10^6$ gm cm^{-2} s^{-1} ilst the accepted value for X-cut quartz vibrating in a ckness mode is $1\cdot44 \times 10^6$ gm cm^{-2} s^{-1}. Thus, provided at good mechanical contact obtains between the quartz d duralumin surfaces then the composite bar thus formed ll behave as a continuous one as far as longitudinal pulses e concerned. Sufficiently good mechanical contact is hieved by careful grinding and lapping of the bar faces d either wringing the faces together with Vaseline or menting with an Araldite resin.

A diagram of the pressure bar and its housing is shown in g. 1. The material of the bar is duralumin and has a rcular cross-section of diameter $\frac{1}{4}$ or $\frac{1}{2}$ in. The X-cut uartz disk *Q* which is wrung on or cemented to the bar ces is of the same diameter as the bar; the disk thicknesses enerally used are $\frac{1}{16}$ or $\frac{1}{32}$ in. The first section *A* of the omposite bar is held by two Weston oil seals *W* fitted into brass cylinder *C*, which slides into the main housing *D*; his cylinder is pressed against an O-ring seal, set in *D*, by screw cap *E*. The head of the gauge can be screwed into a ush set in the wall of the explosion tube. A plug of “Fluon” *F* is set into the measuring end of the gauge through which s drilled a hole which is concentric with the two Weston oil eals and whose diameter provides an easy fit for the pressure ar. Fluon possesses excellent heat resisting properties which s the reason for choosing it for the exposed support of the ar in preference to other insulating material; it is found to ithstand well the high temperatures encountered in detonation aves. The first section of the bar is earthed whilst the econd, *B*, forms the insulated electrode and is surrounded by n earthed shield. This second section of the bar is supported n adjustable V-blocks and a rigidly fixed stop is placed at s free end to prevent the whole bar moving out of the housing hen a pressure pulse is applied to the end *F*; the supports nd stop are not shown in the diagram. A length of between and 12 in. is generally found convenient for *A* whereas the length of *B* is determined by the duration over which it is desired to record. Since the velocity of longitudinal waves in duralumin is $\sim 5 \cdot 10^5$ cm s^{-1}, a bar 2 ft long will enable a signal of approximately 240 μs duration to be recorded before the return of the reflected pulse of tension from the free end; this was normally the length of the section *B*. The charge developed by the crystal produces a voltage across the insulated electrode and this is fed into a cathode-follower by a coaxial line and recorded on a Solarscope type CD 513 oscilloscope.

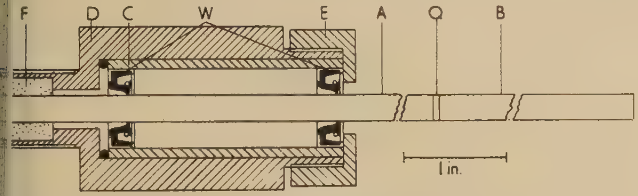

Fig. 1. Diagram of the duralumin pressure bar and housing (supports of bar *B* not shown)

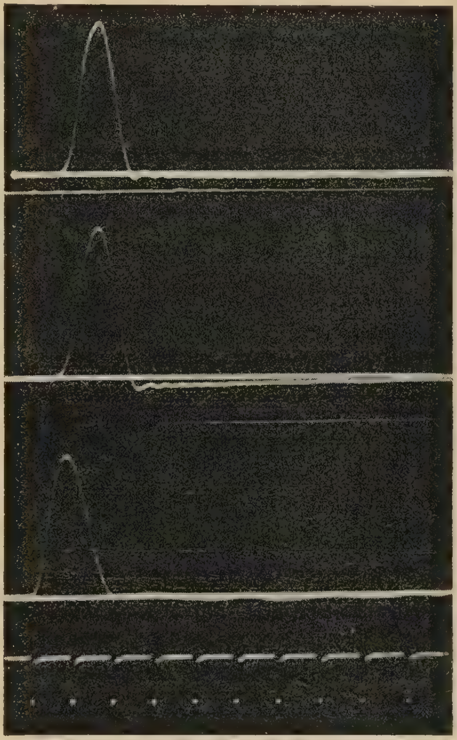

Fig. 2. Oscillograms showing pressure/time relationship of stress pulses, generated by the impact of a steel ball, in a duralumin-quartz pressure bar

(*a*) pressure end of bar is free; (*b*) pressure end of bar surrounded by rubber and clamped in a vice; (*c*) bar fitted into housing shown in Fig. 1. Intervals between time-marker pulses are 20 μs.

In any application of the pressure bar which requires the introduction of the measuring end of the bar into a rigid wall the design of the housing or seating is of paramount importance. Thus in the present work the seating must satisfy the following requirements: (i) it must provide a good vacuum seal between the bar and the tube, (ii) the bar must be mechanically insulated from the explosion tube wall to prevent transmission of stress pulses propagating in the latter from reaching the bar, and (iii) it is essential that the thrust exerted by the seating on the lateral surface of the bar be kept as small as possible in order to permit free radial movement of the surface. In order to stress the importance of condition (iii) some oscillograms of records are shown in Fig. 2 which were obtained in the course of tests carried out on the present housing. Stress pulses were generated in the bar by the impact of a steel ball on the measuring end of the bar. The first record [Fig. 2(*a*)] is the crystal response when the end of the bar is free, whereas the second [Fig. 2(*b*)] was that obtained when about 1 in. of the cylindrical surface of the bar near the impact end was surrounded with soft rubber and clamped in the jaws of a small vice to simulate the effect of a tight seating. It is seen that the effect of constraining the lateral surface of the bar in this way is to cause a tension to follow the main compression pulse and in addition a false peak pressure and pulse shape are recorded. The oscillogram shown in Fig. 2(*c*) was obtained when the bar was fitted into the housing and subjected to a similar impact. Here the disturbing effect of the seals on the stress pulse is negligibly small and only a long period oscillation of very small amplitude appears after the pulse which is probably due to the vibration of the housing. Hence it is felt that this type of mounting is perfectly satisfactory and fulfils all the essential requirements.

THE DURALUMIN-LEAD BAR GAUGE

A more compact form of gauge was developed from the arrangement shown in Fig. 1 by substituting a lead bar for the second duralumin bar *B*. The acoustic impedance of lead has a value of $1{\cdot}42 \times 10^6$ gm cm^{-2} s^{-1} which is a very close match to the value appropriate to the thickness mode of X-cut quartz and the suitability of a lead bar as a backing for the crystal was tested experimentally and was found to be satisfactory. The advantage of using lead instead of duralumin for the second bar lies in the fact that the velocity of longitudinal waves in lead is $1{\cdot}25 \times 10^5$ cm s^{-1} compared with $5{\cdot}0 \times 10^5$ cm s^{-1} in duralumin, consequently the second section *B* may be reduced in length in the ratio of these velocities, namely $\frac{1}{4}$, in order to achieve the same delay in the return of the tension pulse reflected from the free end of the bar. The length of the first duralumin section *A* was also reduced to 2 in. since, as Ripperger(6) has shown, a length of approximately eight bar diameters from the measuring end is sufficient to ensure that the effect of even a concentrated applied force will have spread uniformly over the cross-section of the bar. A diagram of a section of the duralumin-lead gauge is shown in Fig. 3. The pressure bar is supported by three Weston oil seals fitted into the brass cylinder *C* and the whole bar is enclosed in a brass housing *D*. The lead bar *B* is 6 in. long and forms the insulated electrode; the bar *A* is earthed through the inner cylinder *C*. An ebonite cap *E* holds *C* in position and the gauge signal is taken off the lead bar through a screw *G* in the ebonite cap. The construction of the head of the gauge is very similar to the one given in Fig. 1.

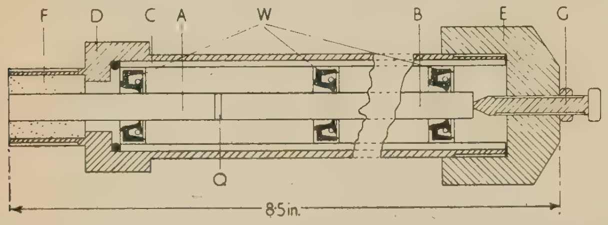

Fig. 3. Sectional view of the duralumin-lead pressure bar gauge

CALIBRATION OF THE GAUGE

The gauge is calibrated by a method described by Davies(2) for the calibration of pressure bar capacitor gauges. For this purpose the two duralumin bars and crystal are removed from their housing and supported in a light aluminium carriage, of approximately the same length as the bars, which is suspended as a ballistic pendulum. A stress pulse is initiated in the bars by the impact of a steel ball, of $\frac{1}{2}$ $\frac{1}{4}$ in. diam., on the measuring-end and the resulting volta pulse from the quartz disk is recorded. In addition, ballistic throw of the system is recorded by means of stationary plate camera.

If *Q* denotes the charge liberated by the quartz disk area *A*, due to an applied pressure *P*, then $Q = d_{11} A$ where d_{11} is the appropriate piezo-electric modulus. T momentum of the stress pulse is given by $A\int_0^\tau P\,dt$ where is the duration of the pulse; this momentum can be equat to the momentum acquired by the suspended system. Th

$$A\int_0^\tau P\,dt = \frac{C}{d_{11}}\int_0^\tau V\,dt = MU$$

where *C* is the total capacity across the crystal, *V* the volta at any instant, and *M* and *U* represent the total mass of t two bars and carriage and their initial velocity after impa respectively. Provided that the ballistic throw X_b is sm compared with the length of the suspension wires then t relation $U = 2\pi X_b/T_b$ obtains, where T_b is the period free vibration of the system.

Hence $$d_{11} = \frac{CT_b}{2\pi M}\int_0^\tau \frac{V\,dt}{X_b}$$

The quantity $\int_0^\tau V\,dt$ is found directly from the pulse recor on the c.r.o. An example of the values obtained in a typic calibration is given in Table 1.

Table 1. *The results of a dynamic calibration of a quartz disk*

Quartz disk, diam. $\frac{1}{2}$ *in. Thickness* 1/16 *in.*

Ballistic throw (*cm*) X_b	$\int_0^\tau Vdt$ (*V s*) × 10⁶	$\int_0^\tau \frac{Vdt}{X_b}$ (*V s cm*$^{-1}$) × 10⁶	d_{11} (*C*/*kg*) × 10¹¹
3·73	26·29	7·05	2·14
3·73	26·23	7·03	2·13
3·73	25·81	6·92	2·10
3·77	26·15	6·94	2·10
3·74	26·65	7·13	2·16
		Mean	2·13

The values of d_{11} obtained by the above impact metho agree to within ±1% with those obtained in a static cal bration described by Edwards and Breeze.(7)

RESULTS

The gauges described above have been successfull employed to measure both the static and reflexion pressure in detonation waves in a variety of gaseous mixtures over range of pressure between approximately 15 and 100 atm Some examples of (pressure-time) distributions obtained wit the gauge in hydrogen–oxygen waves have been describe by Edwards and Williams.(8) A typical oscillogram obtaine by the pressure bar when arranged to measure the stati pressure in a detonation wave propagating in a stoichiometri hydrogen–oxygen mixture, contained in a 4 in. diam explosion tube, is shown in Fig. 4. For a period of approximately 25 μs following the initial rise, there occur a train o oscillations of progressively decreasing period. Thes oscillations arise from the dispersion of the stress pulse a ravels along the bar and are not due to any housing ations. A detailed analysis of the various modes of ation in cylindrical bars is described by Davies,(2) and tis(9) has shown that when shock waves are used to iate stress waves in a bar both the first and second gitudinal mode vibrations are excited. Oscillations due lispersion appearing in the recorded pulse can, therefore,

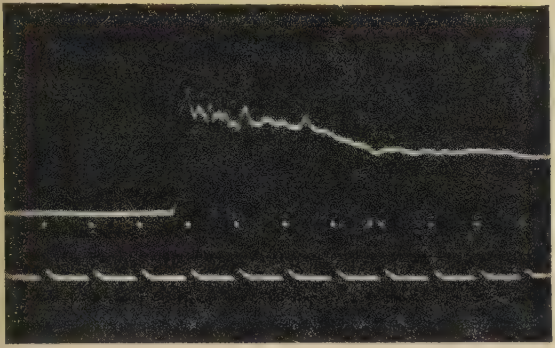

Fig. 4. Oscillogram obtained with gauge shown in Fig. 1 when set to measure the static pressure in a detonation wave in a stoichiometric hydrogen–oxygen mixture in a 10 cm diam. explosion tube. Intervals between time-marker pulses are 20 μs

identified and distinguished from oscillations which may cur in the wave being measured, provided that their quencies are not too close to the bar frequencies. Another int worth noting is the complete absence of vibrations due flexural or non-symmetrical stress waves in the record of g. 4 since the resultant polarization produced in the quartz sk at any instant due to such waves is zero. This is a nsiderable advantage of the method since it obviates the e of long pressure bars to separate the longitudinal and xural waves on the record,(6) and of two surface strain uges to cancel their effects.(10)

To illustrate the accuracy obtainable with the gauge some sults are given in Table 2 of the calculated and measured lues of the static and reflexion Chapman–Jouguet pressures a detonation wave in the mixture $H_2 + O_2$.

Table 2

Mixture $H_2 + O_2$. *Explosion tube 4 in. diam. Initial pressure 1 atm.*

Static pressure (calc.) (atm.)	*Static pressure (obs.) (atm.)*	*Reflexion pressure (calc.) (atm.)*	*Reflexion pressure (obs.) (atm.)*
17·63	17·81	41·82	41·32
	18·26		38·91
	17·72		39·20

It is seen that the three results quoted for the static pressure how very little spread and they compare favourably with the theoretical value. Reasonable consistency is also found between the three measured values of reflexion pressure, which makes far more severe demands on the gauge than the static pressure.

ACKNOWLEDGEMENTS

It is a pleasure to thank Dr. G. T. Williams and Mr. J. C. Breeze for their assistance with the experimental work. The author would also like to acknowledge his indebtedness to the University of Wales for an I.C.I. research fellowship.

REFERENCES

(1) Gordon, W. E., and Mooradian, A. J. *J. Chem. Phys.*, **19**, p. 1166 (1951).
(2) Davies, R. M. *Phil. Trans Roy. Soc., A*, **240**, p. 375 (1948).
(3) Edwards, D. H. *The measurement of pressure in detonation waves in various gaseous mixtures.* Unpublished thesis, University of Wales (1949).
(4) Davies, R. M., Edwards, D. H., and Thomas, D. E. *Proc. Roy. Soc., A*, **204**, p. 17 (1950).
(5) Thomas, H. W. *Gaseous detonations.* Unpublished thesis, University of Wales (1954).
(6) Ripperger, E. A. *The propagation of pulses in cylindrical bars.* Technical report No. 13, N6-NOR-251. Division of Engineering Mechanics, Stanford University, California (1952).
(7) Edwards, D. H., and Breeze, J. C. *J. Sci. Instrum.*, **34**, p. 419 (1957).
(8) Edwards, D. H., and Williams, G. T. *Nature* [*London*], **180**, p. 1117 (1957).
(9) Curtis, C. W. *Amer. J. Appl. Phys.*, **25**, p. 928 (1954).
(10) Davies, R. M. *Surveys in Mechanics*: *G. I. Taylor 70th Anniversary Volume* (Ed. G. K. Batchelor and R. M. Davies). "Stress Waves in Solids," p. 64 (London: Cambridge University Press, 1956).

Laboratory and workshop notes

Electrodes for thin metal films

By S. Chandra and G. D. Scott, Department of Physics, University of Toronto, Canada

[*Note first received* 14 *January, and in final form* 24 *February*, 1958]

o provide electrodes for thin evaporated films, it is common ractice to use a heavy metal coating evaporated on the ubstrate and overlapping the test film. Wire connexions to he heavy coatings are then made with the aid of metal foil r by tin-lead soldering, which may result in mechanical or hermal damage to the coating. Belser's technique* of oldering directly to the test film with a tin-indium alloy melting point 116° C) is apparently successful with thicker films, but may not be suitable for films near or less than the "critical" thickness.

The techniques described below have been developed to avoid some of the uncertainties which can arise with the previous methods. For both temperature ranges the procedure was to fasten copper wires to the glass, and then evaporate a heavy coating of silver to provide contact between the wire and the test film, which was deposited so as to overlap the heavy coating.

For work at temperatures less than 100° C, an indium alloy Cerroseal-35 (available from the Cerro de Pasco Corp., New York) was employed as a solder. A small pencil type of soldering tool was used in series with a rheostat to control the temperature at its tip. No flux is needed for this solder, but it is important that the glass and the copper wire be thoroughly cleaned.

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* Belser, R. B. *Rev. Sci. Instrum.*, **25**, p. 180 (1954).

Strips of glass of suitable size are cut from microscope slides and cleaned by putting them in dilute nitric acid for about an hour, washing the acid off in running water, rinsing them well in a detergent, washing them again in hot water, keeping them overnight in chromic acid and finally washing them first in hot running water and then with distilled water. The ends of such strips are then coated with a thin layer of Cerroseal with the help of the soldering tool. The solder flows on the glass quite easily and uniformly.

Short lengths of 18 s.w.g. copper wire are cut and a small loop formed at one end of each. The loops are flattened in a vice to give greater surface contact with the glass and are then cleaned in dilute nitric acid which must be thoroughly rinsed off. The side of the loop which is to be in contact with the substrate is coated with solder. The loop is then put on the substrate and pressed with the hot tool which melts the solder and lets it flow below and around the electrode. Moving the tip of the soldering tool around the loop gives a gradual slope to the solder between the electrode and the substrate.

When an electrode has been fastened at each end of the glass strip a heavy coating of silver is evaporated over the loop, the surrounding solder and the glass. The desired area for the test film is masked off between the electrodes. The thickness of the heavy coatings should be 3000 Å or more.

Cerroseal is a low melting point solder and cannot be used on substrates to be taken much above 100° C. For higher temperatures, Araldite has been employed quite successfully to cement copper wire to the glass. Once baked, Araldite can stand temperatures up to 250° C. In this case, the ends of the pieces of 18 s.w.g. copper wire are flattened rather than looped to give a large mechanical contact with the substrate.

A thin paste of Araldite is applied to the flattened surface of the copper wire and one end of the glass strip is then put on it. Slightly heating the wire by a small flame melts the Araldite which then flows between the electrode and the substrate. On cooling they are temporarily joined. For good electrical contact the Araldite should form a gradual slope at both the copper and the glass. When the electrodes are thus cemented to both ends of a strip, permanent joints are made by baking the strip in a furnace at 200° C for 40 min.

Since there is a possibility that the glass surface may become contaminated with vapours during the baking, the glass strips should again be cleaned as described above. Baked Araldite is not acted upon by the acids used. As before, the final step is to evaporate a heavy coating of metal over the copper electrodes, cement and glass, leaving the desired area for the test film.

Though single heavy gauge wire has been used in our experiment, stranded copper wire could be employed either directly or soldered to the heavy wire in order to provide flexible leads and to reduce stresses at the joints.

An electrode holder for the porous cup technique of spectrographic analysis

By G. W. J. Kingsbury and Anita Fursey, Chemical Research Laboratory, Teddington, Middlesex

[*Note received* 24 *December*, 1957]

Several analytical problems encountered in this laboratory have necessitated the use of the porous cup technique,* and it was found that the electrode holders available were very subject to corrosion by the solutions, electrode changing w slow and where springs were necessary to the constructi these quickly deteriorated. The electrode holder descri was therefore designed to be self alining, corrosion resista quick in operation and require little maintenance.

The complete electrode holder assembly is shown in Fig the electrodes, upper and lower, being held in the V-shap grooves which maintain good thermal and electrical cont

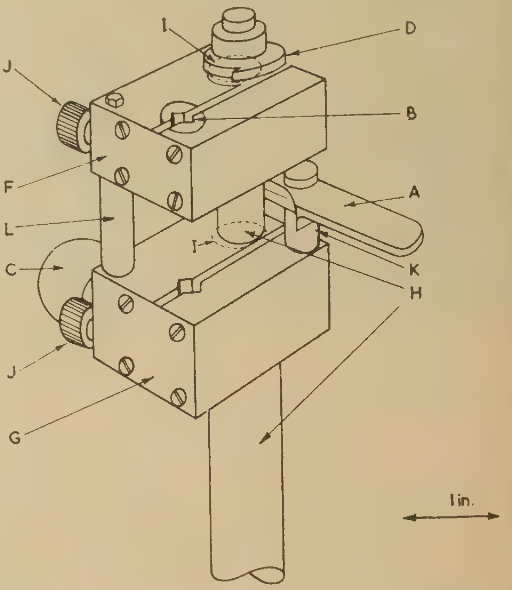

Fig. 1. Complete electrode holder assembly

despite the usual slight variations in diameter of graphite an carbon rods. The electrode clamps were made of stainle steel, but, where contact was made with the porous cu electrode, tantalum inserts *B* were fixed with tantalum pi The shaft *H* and cams *I* about which the assembly turns we made of insulating material, as was the rod *L* which joi together the two electrode clamps. This rod maintains fixed distance between the clamps and ensures that the move simultaneously. Bakelite/linen laminated material wa used for the shaft, cams and rod, but there was a tendenc for high-voltage flashover to occur along the surfaces of and *H* when made wet with spray from the spark-gap, thoug polythene sheathing fitted to the rod and shaft between th clamps cured this fault. (Nylon or P.T.F.E. rod woul probably be suitable without this additional sheathing The springs *F* and *G* were made of 21 s.w.g. phosphor bronz strip, and all metals parts other than the terminals *J* and th V-grooves in contact with the electrodes were coated wit epoxy resin before assembly to provide protection fro attack by acid solutions.

In operation each electrode is held by spring tension in th clamps which are released simultaneously by rotating th

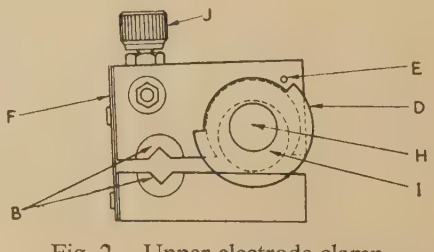

Fig. 2. Upper electrode clamp

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* Feldman, C. *Analyt. Chem.*, **21**, p. 1041 (1949).

ıplete assembly about the eccentric cams fixed to the shaft. :se two cams operating the upper and lower clamps are ially positioned for the electrodes it is desired to use, and ced to the shaft with grub-screws. The upper and lower :trodes need not have the same diameter. The amount of ıtion is governed by the pin E and stop D (Fig. 2), this er being fixed to the main shaft and so adjusted that in closed position the electrodes are automatically alined the optical axis. The shaft is held in the usual optical ıch saddle-stand.

'o load the electrode holder the assembly is turned to the :n position (Fig. 2) and a Perspex spacer A on an insulated ot K fastened to the lower pair of jaws is swung until it is ween the upper and lower V-shaped grooves, the thickness this spacer determining the size of the spark gap. The ous cup electrode is placed between the tantalum inserts n the upper clamp so that the electrode is resting on the Perspex spacer. A counter electrode is held in position through the opening in the lower clamp with its apex against the under surface of the spacer. Using the handle C, attached to the lower clamp, the electrode holder is rotated horizontally about the cams, the clamps thus closing. When the spacer is swung away from the spark gap the electrodes are retained in position by the spring tension of the phosphor-bronze strips. The electrodes are released by rotating the assembly in the reverse direction.

An electrode holder of this pattern has given trouble-free service for over three years and, while it was designed specifically for the porous cup technique, it could also be used for other spectrographic analyses employing spark discharges and rod electrodes.

We wish to express our thanks to the Director, Chemical Research Laboratory, for permission to publish this note.

NOTES AND NEWS

Correspondence

A precise reference inductor

. Gugan[(1)] suggests the use, as a reference standard, of an luctor wound on a ferromagnetic core of a material which ırates abruptly (such as H.C.R. alloy or Permalloy F). ıe saturation flux density of these materials varies with nperature, however; the variation is of the order of 2% tween 0 and 100° C. This variation can be compensated, d the flux density made even less dependent on the applied ld, by using two ferromagnetic cores with primary windings series and secondary windings in series opposition. The ıin core should be of a rectangular-loop material such as C.R. or Permalloy F, and the additional core of an alloy ving a lower Curie temperature and therefore a greater variıion of saturation flux density with temperature. Mumetal or rmalloy C can be used for the second core, but better sults can be obtained by using an alloy designed for the ırpose, such as Alloy A in the table, which contains 76% ckel, 12·5% iron, 6·5% molybdenum and 5% copper. ıe table gives the relevant data.

Variation of saturation flux with temperature in various alloys

Alloy	*Curie point (°C)*	*B_{sat} at 0° C (G)*	*Fall of B_{sat} between 0° and 100° C (cal.) (G)*	*Typical ratio B_{rem}/B_{sat}*
.C.R.	510	15 000	440	0·95
ermalloy F	600	12 500	200	0·95
lumetal ermalloy C	390	8 000*	460	0·7
lloy A	300	6 200	600	0·7

* Reference books quote $B_{sat} = 6500$ for Mumetal, but I believe)00 to be more nearly right.

If, then, an inductor is wound on a core of Permalloy F, nd is opposed by an inductor having the same numbers of ırns and a core of Alloy A of similar magnetic path-length ut only one-third of the cross-section, the result will be as the inductor were wound on a core having $B_{sat} = 10\,400$ t both 0° and 100° C. Further, the net variation of output ith applied field will be reduced, since the output from the core of Alloy A will vary with field more rapidly than that from the main core. The ratio B_{rem}/B_{sat} quoted in the table gives a rough indication of this effect, though it is not exactly the relevant quantity; in any case this ratio can be varied by the heat-treatment given to the cores at the final stage of manufacture.

A similar combination of magnetic cores can be used in saturable-core transformers, used for stabilizing an alternating voltage, to overcome the variation of output voltage with temperature.

Post Office Engineering Research Station, A. C. Lynch
Dollis Hill, London, N.W.2. [14 February, 1958]

Note added 15 *May*, 1958: This method of compensation is applicable also to the decade flux-linkage generators described by Palmer,[(2)] and would overcome a difficulty which he mentions in his paper.

REFERENCES

(1) Gugan, D. *J. Sci. Instrum.*, **35**, p. 31 (1958).
(2) Palmer, T. M. *J. Sci. Instrum.*, **35**, p. 139 (1958).

For the purpose of standardizing mutual inductors, it is probably most convenient to avoid temperature effects in the ferromagnetic inductor by enclosing it in a non-conducting sheath surrounded by an ice bath. This was done in the original work an an inductance constancy of about 1 in 10^5 was easily attained. However, Mr. Lynch's suggestion could certainly have useful application in some cases. By a suitable combination of three or more ferromagnetic inductors with their primary windings connected in series it should, for instance, be possible to produce an inductor which is almost exactly compensated for quite large changes in both magnetizing field and temperature. It would be important to have all the ferromagnetic cores magnetized in their regions of technical saturation because only then is a highly reproducible output obtainable.

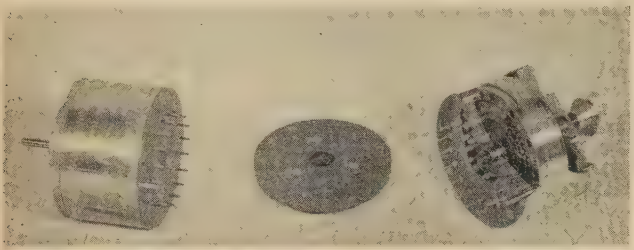
National Research Council, D. Gugan
Ottawa, Canada. [6 May, 1958]

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impro products. The Institute of Physics assumes no responsibility for the statements given below: information for these has b taken from literature supplied.

Multi-turn digitizer. Harrison Reproduction Equipment Ltd., 7 Camp Road, Farnborough, Hants.

The Harrison multi-turn digitizer expresses in a coded decimal form the angular position of its driving shaft at any point within 100 turns. It has two disks which are geared together so that the ratio of their movement to each other is 100 : 1. Metal balls are pressed on to the patterns on the disks and on to other stationary metal patterns to form complex circuits which are connected to the 18 pins at the back of the instrument. When the disks are rotated the circuits are changed between conducting and non-conducting states in accordance with a certain code. This code, in which the combinations of binary variables representing adjacent whole numbers differ on only one variable, and each variable changes only twice per decade, is suitable for relatively simple relay or electronic methods of decoding. It is known as the Petherick Cyclic Permuting Binary Coded Decimal. A decade 0/9 is represented by four circuits *WXYZ* made in the sequence *XZ*, *Z*, *YZ*, *Y*, *XY*, *WXY*, *WY*, *WYZ*, *WZ*, *WXZ*. Each of the two disks in the instrument controls the circuits for two decades, and the whole device therefore divides 100 revolutions into four decades. An angular precision of 20″ is claimed. The unit is approximately 2 in. diameter and 1½ in. deep.



Multi-turn digitizer. Complete unit and section showing interior

Dew-point meter. Electric Resistance Furnace Co. Ltd., 161 Queens Road, Weybridge, Surrey.

The Alnor dew-point meter is a portable, self-contained instrument, manually operated and designed for the measurement of the water vapour content of any gas which has a dew-point within the range −80° F to room temperature. The apparatus operates on the principle that if a gas is compressed and the pressure released, the consequent expansion results in a cooling effect. If the expansion is sudden, adiabatic conditions are approached so that final temperature can be calculated. By means of a buil hand pump, a sample of the gas is drawn into the instrum and held in the observation chamber above atmosphe pressure. The temperature and pressure of the gas are th read and the pressure quickly released by depressing operating valve. This also switches the lamp on, illuminat the chamber. If the gas has cooled to the dew-point due its rapid expansion, a fog will be observed through window. A radioactive foil in the expansion chamber p duces ions to act as condensation nuclei in the absence dust particles. The actual dew-point temperature is re from a slide-rule calculator which gives the relations between initial temperature, pressure ratio and dew-point

Dew-point meter

British Journal of Applied Physics

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A decade of stable resistors for calibration of the Smith resistance thermometry bridge (type 3)

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[*Paper first received* 29 *April, and in final form* 4 *November*, 1957]

A decade of highly stable 10 Ω resistors employing a new method of construction is described. The bare manganin wires are wound on Pyrex glass tubes which are assembled in such a way as to permit annealing (at 420° C) and pickling of the whole assembly. The resistors are adjusted after being annealed, and are then pickled and sealed into a Pyrex glass envelope without being further disturbed.

The lead resistance characteristics demanded by the balance equation for the Smith bridge (type 3) are discussed, and the calibration and use of the decade for checking the bridge are described.

he Smith resistance thermometry bridge (type 3) used in e Defence Standards Laboratories is subject to irregular esistance drifts which can result in errors in temperature easurement exceeding ±0·002° C between 0° and 100° C nd ±0·01° C at 630° C. However, it has been shown lsewhere⁽¹⁾ that these errors can be reduced to ±0·0005 nd ±0·001° C respectively by using the bridge to measure arious sections of an external decade of 10 Ω resistors, a imple process which can be repeated as often as required.

The requirements of such a calibrating decade are that the alues of its resistors should be known relative to one another o one part per million (p.p.m.), and that certain conditions elating to its lead resistances should be satisfied, since the Smith bridge is a double bridge. In addition, for checking he bridge during long-term measurements on the reproducibility of certain fixed points (e.g. the triple point of water and the freezing point of zinc) to an accuracy of ±0·0001° C or better, the drift rates of the calibrating resistors should be monotonic and small enough to enable their drifts over the relevant periods to be estimated to within a few parts in 10^7.

In developing this decade, it was hoped to achieve even better stability than had then been reported (late 1954) by Barber, Gridley and Hall⁽²⁾ by supporting the bare manganin resistor coils in such a way as to allow of the complete resistor assembly being annealed and pickled, and then sealed without further disturbing the resistors. This introduced the requirement that the resistor formers and supporting structure should be capable of withstanding the annealing temperature (about 420° C) and subsequent pickling in an acid solution, as recommended by Schulze.⁽³⁾

DESIGN AND CONSTRUCTION

The method of construction of the resistor assembly is shown in Fig. 1. The ten resistors (7) of 34 s.w.g. bare manganin wire (by Driver Harris Co., U.S.A.) are loosely wound on Pyrex glass tubes (8), leaving loops (10) for adjustment purposes. The ten tubes are held in a cylindrical cage formation by three mica disks (6, 9) and a Pyrex glass rod (11). The resistors are hard-soldered together in series, with a copper lead (5) to each junction and two copper leads to each end (see Fig. 2). The provision of only one lead to each junction reduces considerably the number of connexions to be brought out through the glass envelope into which the assembly is subsequently sealed. (Although the Smith bridge is a double bridge, it is shown below that no significant error results from not having two leads to each junction.)

In order to establish the initial values and the subsequent post-annealing adjustment of the resistors required to give the desired values after pickling, it was necessary to carry out some preliminary experiments. Results for a typical coil are shown in Table 1. Unfortunately, the precise effect of the pickling treatment on the resistance values was not easy to control, and the final values of the decade resistors, measured after a thorough washing, turned out to be

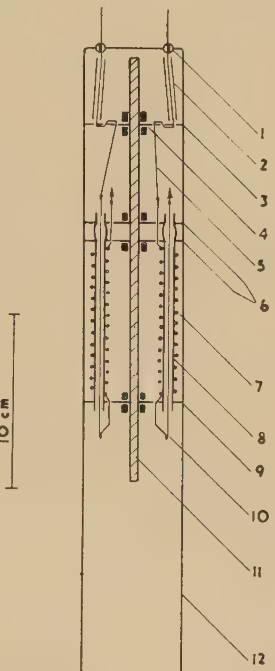

Fig. 1. Vertical section of resistor assembly

(1) lead-wire seal (Araldite, copper tube, solder); (2) Pyrex glass insulator; (3) mica disk; (4) nickel collar; (5) copper lead-wire; (6) mica disks; (7) manganin resistor; (8) Pyrex glass former; (9) mica disk; (10) adjusting loop; (11) Pyrex glass rod; (12) Pyrex glass envelope.

10·055 Ω ± 0·01 Ω (see Table 2), i.e. about 0·04 Ω higher than was originally intended. This was considered acceptable, however, as the whole decade could still be balanced on the Smith bridge without using more than 54·1 Ω from the lower dials of the bridge.

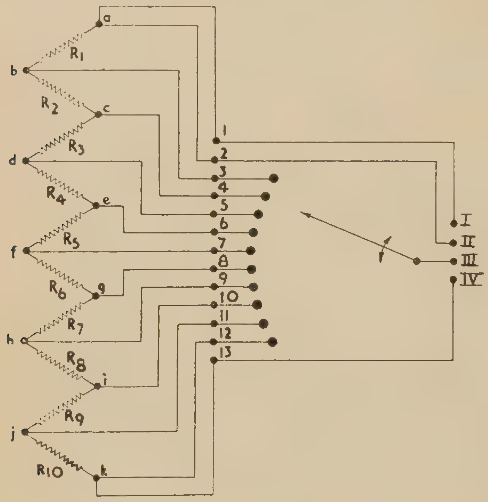

Fig. 2. Circuit diagram of decade

Table 1. *Adjustment of an experimental resistor*

Stage	*Resistance (Ω*
Initial value	12·0
After annealing in hydrogen at 420° C for 2 h	10·5
After adjustment by shortening loop (10) (see Fig. 1)	9·94
After pickling for 30 s in weak chromic acid* at 20° C, and washing	10·02

* 1000 ml. of water + 1 g of potassium chromate + 9 ml. concentrated sulphuric acid.

Table 2. *Measurements on decade resistors (at 28° C), relative to 10 Ω standard*

Resistor No.	*Initial value (Ω) Dec. 1954*	*Drift relative to initial value (p.p.m.)* *April 1955*	*July 1955*	*Dec. 1955*	*Sept. 1956*	*Aug. 1957*
R_1	10·055 73	6	8	11	22	29
R_2	10·061 83	6	8	12	24	34
R_3	10·067 39	7	10	14	24	33
R_4	10·060 17	7	9	11	24	31
R_5	10·055 31	7	10	14	26	34
R_6	10·057 72	7	9	13	23	33
R_7	10·057 59	6	8	12	22	32
R_8	10·065 41	6	9	13	25	36
R_9	10·045 47	8	10	12	26	35
R_{10}	10·049 62	6	9	12	25	34

The resistor assembly is sealed into a Pyrex glass envelope (12, Fig. 1). To avoid undue heating of the resistors during the sealing of the lower end of this envelope, it was made about 15 cm longer than the resistor assembly. The thirteen copper leads (5) of the latter are sealed (with solder) through thirteen small copper tubes (1) which had previously been cemented with Araldite into small holes in the upper end of the envelope. The whole resistor assembly hangs by these leads, but they are so arranged that no strains are transmitted to the resistors. Before being sealed off, the completed unit was evacuated for several days to ensure thorou drying, and was then filled with dry nitrogen.

The various connexions are shown in Fig. 2. For highe precision measurements external connexions can be ma direct to the appropriate terminals (1 to 13), but for ease everyday operation a selector switch is also provided. I eleven contact studs are each 8 mm diameter and its conta resistance variation, when oil immersed, is less than ±30 μ The unit (see Fig. 3) is mounted in a stirred oil bath, th

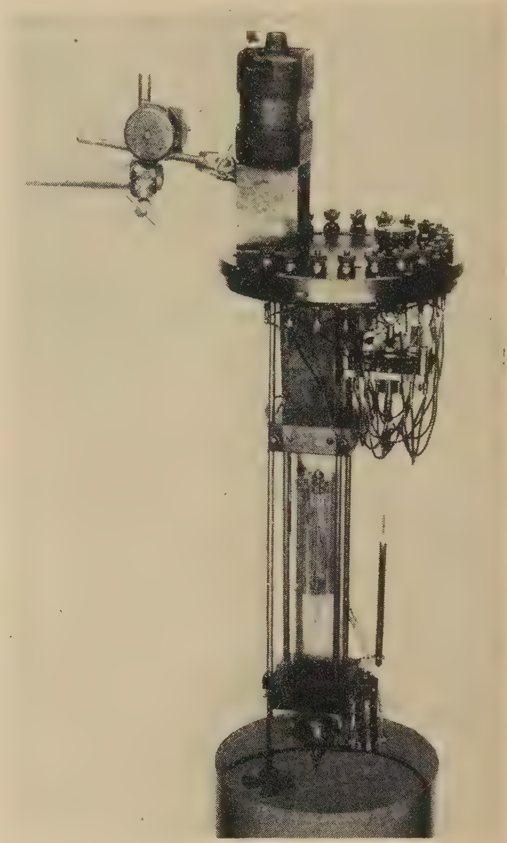

Fig. 3. The complete decade unit, about to be lowered into its oil bath

temperature of which is controlled at 28° C by means of a contact thermometer and an electronic switch. The temperature coefficient of the resistors goes through zero between 25 and 26° C, but 28° C was adopted as the operating temperature in order to ensure satisfactory control during the summer months; at this temperature the coefficient is still under −2 p.p.m. per ° C.

THE EFFECT OF LEAD RESISTANCE INEQUALITIES

The Smith bridge circuit is shown in Fig. 4. At balance

$$P = \frac{R}{S}(Q + L_3) + \frac{bL_2}{a + b + L_1 + L_2}\left(\frac{Q + L_3}{S} - \frac{a + L_1}{b}\right)$$

Subject to certain conditions,(4) this equation reduces to

$$P = (R/S)Q$$

The conditions which are important in this context concern the leads L_1, L_2 and L_3: their resistances should be equal and should be very small compared to the sum of the resistances in the a and b arms.

The circuit of the decade is so arranged (see Fig. 2) that resistors R_1 to R_{10} can be measured individually or in quential combinations using terminals 1 to 13, or in the quential combinations R_1, or $R_1 + R_2$, or $R_1 + R_2 + R_3$, ., by connecting the bridge to terminals I to IV and using e selector switch to successively add further resistors. oviously, the sum of measurements on individual resistors ll agree with the corresponding group measurement only the requirements for lead resistance equality are satisfied. ince, in some instances, these calibrating resistors are xpected to check on the value of the Q arm of the bridge o 0·001 Ω, L_2 should equal L_3 to better than that figure. This order of equality must therefore be realized for all eads of the decade between junctions a to k and the corresponding terminals 1 to 13, as well as for their continuations rom these terminals to terminals I to IV, including contact esistance in the selector switch, which is part of L_3.

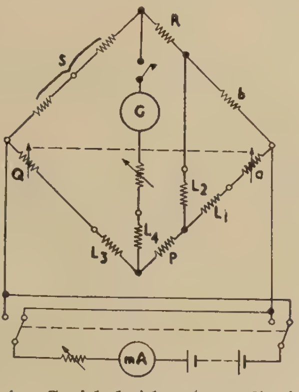

Fig. 4. Smith bridge (type 3) circuit

$S = b = 1000\ \Omega$, $R = 10\ \Omega$, $a = (Q + 10)/0\cdot99\ \Omega$, P = thermometer, L_1, L_2, L_3, L_4 = thermometer leads.

Concerning L_1, it will be obvious that measurements of ıny one of resistors R_2 to R_9 of the decade are not possible on the Smith bridge unless a neighbouring 10 Ω resistor is included into this lead. However, it can be shown that provided L_2 and L_3 are less than 0·2 Ω, this relatively high resistance of L_1 does not introduce an error greater than 100 p.p.m. into the resistance under measurement. Moreover, this error varies only by about ±1 p.p.m. if L_1 changes by ±1%. In the present decade L_2 and L_3 are only just over 0·1 Ω and the ten resistors are equal to within ±0·01%. Therefore, any one of them can be made part of L_1 without significantly affecting the magnitude of this error. This magnitude can be determined while measuring either R_1 or R_{10}: connexion to R_1 *via* terminals 1, 2, 3 and 4 will give results free of the error, while connexion in the reverse order will introduce it. Hence, it can be evaluated from the difference between these two measurements. Similarly, it may be determined from measurements on R_{10}.

CALIBRATION AND PERFORMANCE

To ensure relative accuracy, which is all that is required for normal resistance thermometry work, the decade resistors can be compared with each other by simply measuring them singly in terms of the first 1000 Ω dial setting of the Smith bridge. (If the decade resistors are equal to ±0·1%, the setting of the 1000 Ω, 100 Ω and 10 Ω dials will be the same for all ten bridge readings, while the nominal resistance values of the 1 Ω, 0·1 Ω and 0·01 Ω settings, some or all of which may have to be varied, will generally be sufficiently accurate not to affect the precision of these intercomparisons.) Corrections to the sums $R_1 + R_2$, $R_1 + R_2 + R_3$, etc., can then be calculated in terms of the first 1000 Ω bridge setting. The 2000 Ω setting of the bridge can then be checked against $R_1 + R_2$, and the 3000 Ω setting against $R_1 + R_2 + R_3$, etc. If this is done by connecting the bridge to terminals I to IV and using the switch to add successive resistors, the resistors not under test should be short-circuited by a short copper wire connecting terminal 13 to the terminal following the switch position, e.g. to terminal 5 when the switch is connected to terminal 4. Thereby, the additional resistance in the galvanometer branch of the bridge is reduced to 10 Ω in all cases. (This could be done automatically by another selector bank ganged to the existing switch.) Allowance must, of course, be made for the residual resistance of the bridge, i.e. its resistance when all dials are set to zero.

This calibration procedure does not need to be repeated very often, even if the decade resistors should drift significantly, e.g. during the first few months after their completion, provided they all drift in a similar manner.⁽¹⁾ This can be verified by remeasuring them at (say) monthly intervals in terms of the first 1000 Ω Q arm setting of the bridge. Obviously, such a check is not influenced by any Smith bridge drift during the same period.

For the monitoring of a bridge which is to be used for measurements requiring high long-term reproducibility, such as the fixed point measurements mentioned in the introduction to this paper, it is essential that the decade resistors be calibrated at regular intervals against a good standard resistor having an accurately known drift rate. At this laboratory these calibrations are carried out by potentiometric comparison with a well-aged 10 Ω manganin standard resistor which is known not to have changed by as much as 2 p.p.m. during the three years preceding the test period.

The results of some of these measurements are given in Table 2. The initial drift in the six weeks interval before these systematic measurements started is not known precisely, but may have reached 5 p.p.m. The consistent behaviour of all ten resistors is to be noted.

CONCLUSION

The method of construction described here has been applied to only one decade, and although the stabilization rate of the resistors in this unit has proved to be no better than that of the 10 Ω resistors recently described by Barber, Gridley and Hall,⁽⁵⁾ further experience with this method may well lead to improved results. As a unit for the continuous checking of the Smith bridge (type 3), the decade has been very successful.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. C. F. Howie for some useful initial discussions, and to Mr. N. S. Brown for assistance during the construction of this decade. Acknowledgment is also due to the Chief Scientist, Australian Defence Scientific Service, Department of Supply, for permission to publish this paper.

REFERENCES

(1) Lowenthal, G. C. *Brit. J. Appl. Phys.*, **8**, p. 449 (1957).
(2) Barber, C. R., Gridley, A., and Hall, J. A. *J. Sci. Instrum.*, **29**, p. 65 (1952).
(3) Schulze, A. *Metallwirtsch*, **20**, p. 69 (1941).
(4) Smith, F. E. *Phil. Mag.*, **24**, p. 561 (1912).
(5) Barber, C. R., Gridley, A., and Hall, J. A. *J. Sci. Instrum.*, **32**, p. 213 (1955).

Computing plates

By J. de Meulenaer, European Research Associates, s.a., 95 rue Gatti de Gamond, Brussels, Belgium

[*Paper first received* 25 *November*, 1957, *and in final form* 7 *May*, 1958]

A simple appliance is described by the aid of which a number can be set mechanically on the keyboard of a desk calculator any number of times.

When carrying out lengthy computations on a desk calculator, it often happens that the same numbers have to be set on the keyboard several times and frequently even many times. We have designed a simple appliance which enables one to set a number on the keyboard any number of times mechanically, thereby saving time and effort and reducing the chances of errors; the basic idea is not entirely new and a similar piece of equipment has been described in the literature previously.(1)

Briefly, the underlying idea is to have a plate or grid on which studs can be displayed in such a way that they represent a replica of the pattern formed by the required number on the keyboard. If the height of the studs equals the distance travelled by the keys on depressing them, a simple application of the plate to the keyboard will depress the appropriate keys and leave the number set. Clearly the process can be repeated as often as required.

In the prototype model which we had constructed, the body of the appliance consists of a bakelite plate with a square array of 9 × 10 holes, corresponding exactly with the keys of our machine. Ledges on two adjacent sides ensure proper positioning of the plate. Studs of appropriate sizes can be fixed on the underside of the plate by passing their threaded shafts through the holes required and fastening them with nuts. The plate can be assembled even more quickly if the shafts of the studs carry grooves; a thin metal plate, of the same size as the main plate and having holes drilled in the same positions, has narrow slots of $\frac{1}{8}$ in. length taken out at each hole, so that the shafts of the studs can pass through the holes of both plates for assembling or dismantling and can be keyed into position by sliding the metal plate so that the slots engage the grooves in the studs. All studs can thus be fixed or released at the same time, so that the whole operation does not take more than a few seconds.

One can easily imagine other constructions based on the same idea, e.g. the plate might be replaced by a frame carrying a number of parallel rods, one for each digit of the full capacity of the keyboard, on which riders can slide to be fixed at the appropriate figures; the appliance described by Horsburgh(1) is of a similar design.

We had sixteen such plates constructed and have used them extensively; we found them particularly useful in matrix calculations where the elements of a matrix are used again and again, and in finding the roots of algebraic equations where the coefficients of the equation occur many times in the course of the calculation.

We have found the rapidity with which the elements of a matrix can be transferred to the keyboard repeatedly such an advantage that we have allowed it to influence our choice of a method to find the latent roots and characteristic vectors: we have in fact found it advantageous to revive Leverrier's old method (see, for example, Ref. 2). Essentially this method consists of calculating the successive powers $J^2, J^3 \ldots J^n$ of the matrix J of order n; the trace s_i of J^i equals the sum of the i-th powers of the roots and the coefficients a_j of the characteristic equation $P(\lambda) = 0$ can calculated from the s_i by the use of Newton's recurre formulae. Computation of J^n is not necessary to obtain t a_j, but is to be recommended, since $P(J) = 0$ (Cayle Hamilton theorem) provides a useful check on the who calculation. The unnormalized characteristic vector corresponding to the root λ_k is obtained by the use of t "annihilator"(3) $P_k(J)$, where $P_k(\lambda) = P(\lambda)/(\lambda - \lambda_k)$, sin $P_k(J)V = Y_k$, with arbitrary vector V. The coefficients $P_k(\lambda)$ have been obtained in the last stage of the calculati of the roots, when verifying that λ_k satisfies $P(\lambda) = 0$; sin the powers of J have also been already obtained, the ca culation of Y_k proceeds very rapidly. Naturally, one choos for V the simplest possible vector, which has one elemen equal to unity and all others to zero; since Y_k is obtaine with maximum accuracy if V is parallel to Y_k, we hav sometimes found it useful to repeat the calculation of with a more suitably chosen unit element of V.

When solving algebraic equations, we have found it usef to have plates with each of the coefficients; the value of polynominal $P(x)$ is then quickly calculated for any value o x by synthetic division. The roots of $P(x) = 0$ are thu quickly obtained, whether one used the *regula falsi* o Newton's method; in the latter case the same plates can b used for the coefficients of the derivative of $P(x)$, since they ar simple multiples of those of $P(x)$ and can be formed by re peated applications of the same plates.

We should like to stress finally that we do not regard th great increase in the rapidity, with which the calculation can be carried out, as the only, or indeed main, advantage o using these computing plates; we have found the increase in the security due to the removal of a major source of errors i.e. the manual setting of the numbers in the keyboard, as an advantage of at least equal magnitude. Clearly, these computing plates can only be used with calculating machines which have a set of nine setting keys for each digital position

ACKNOWLEDGEMENTS

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REFERENCES

(1) Horsburgh, E. M. *Modern Instruments and Methods o Calculations*, p. 129 (London: G. Bell and Sons, Ltd., 1914).

(2) Bodewig, E. *Matrix Calculus*, p. 315 (Amsterdam: North Holland Publishing Company, 1956).

(3) Ref. (2), p. 239.

An electrostatic-magnetic alinement section for the electron microscope

By M. E. Haine, M.Sc., D.Sc., F.Inst.P., A. W. Agar, B.Sc., F.Inst.P., A.M.I.E.E., and T. Mulvey, M.Sc., A.M.I.E.E., Associated Electrical Industries Ltd., Aldermaston, Berks.

[*Paper received* 17 *March*, 1958]

A compact electron beam shift and tilt system, using electric and magnetic fields in place of the normal mechanical system, is described. This improves mechanical stability and permits reflexion electron microscopy up to angles of beam tilt of 20°.

the electron microscope of usual design, the illuminating tem is alined with the other lenses by means of mechanical ing and translation controls. The development of the uble condenser lens, and the provision of a pumping tube o the gun itself in the latest type of instrument, make it onvenient to tilt the illuminating system mechanically, rticularly through the large angles of the order of 20° quired for reflexion electron microscopy. To overcome s difficulty, an alinement system was devised in which the cessary deflexion of the beam is accomplished by a com- nation of electric and magnetic fields. The system was plied to an experimental prototype instrument.

If a purely magnetic deflexion system is employed, the air p spacing of the magnets must be sufficiently great to ow for the passage of the beam for reflexion working. is leads to a bulky and cumbersome system with large flecting coils.

The new deflector system takes advantage of the fact that e large deflexion of the electron beam required for reflexion orking takes place in one plane only; consequently, the le faces of the magnet used for this large deflexion can be osely spaced, provided that the small alinement required the plane at right angles can be provided. This is done by ing the pole faces themselves as electrostatic deflector ates, merely by insulating them electrically from the magnet res. In this way, full alinement could be obtained with a nsiderable economy of space and excitation.

ELECTRON OPTICAL REQUIREMENTS

The alinement system is required to ensure that the central art of the beam from the electron gun should illuminate the ecimen in a region around the objective lens axis. For ansmission work, the illuminating beam should have a egligible inclination to the optical axis of the objective lens; r reflexion, it should be possible to vary this angle from ero to about 20° in one plane only. For transmission work, maximum tilt angle of ±1° is generally sufficient to correct ny gun misalinement. These requirements are met by the rovision of a transverse adjustment (shift) and a tilt of the luminating system with respect to the objective lens. The lt mechanism must be arranged so that the tilt takes place ithout appreciable lateral shift of the beam in the object lane.

MODE OF OPERATION OF THE DEFLECTORS

The action of the deflectors in producing tilt is illustrated n Fig. 1. The beam *SO* is required to be tilted so as to ppear to emanate from S', without moving the centre of the llumination from O. If the centres of the deflector plates re distant d apart, and the lower plates are distant l from the object, then a tilt angle α at the specimen will be obtained when the beam is deflected through an angle θ at the top plates and back through an angle $(\theta + \alpha)$ at the bottom plates, where $\theta = l\alpha/d$. The distance l is largely determined by the design of the specimen chamber, and an upper limit is placed on d by the space allowable for the alinement section. The distance d cannot be made too small compared with l otherwise large values of θ will result leading to aberrations. In the present design, $l \simeq 9$ cm and $d = 3$ cm. The maximum magnetic deflexion of the beam by the lower plates must therefore be about 80° (four times the greatest tilt angle required for reflexion); and the maximum electrostatic deflexion about 4°.

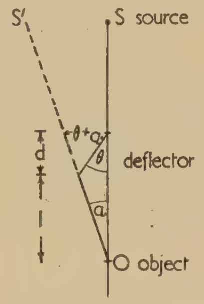

Fig. 1. Method of producing tilt

Translation of the beam ("shift") may be obtained in two ways: (i) the beam may be deflected through an angle θ in the upper plates and back through an angle θ in the lower plates. This results in a shift of the illumination of $\theta . d$ and does not introduce any tilt; (ii) the beam is deflected through an angle θ by the lower plates only, causing a shift of $l . \theta$ $(\simeq 3\theta . d)$ for the same excitation of the deflexion but is accompanied by a tilt θ. This method is more economical in excitation, and, since the tilt adjustment is normally made after the beam has been alined laterally, the small interaction between shift and tilt is relatively unimportant.

MAGNETIC AND MECHANICAL DESIGN

The size of the magnetic circuit of the alinement stage was determined by the necessity of keeping within the limits set by the fixing bolts and vacuum seals of the existing condenser lens and specimen stage. An outer annulus of steel (Fig. 2*a*) was made to accommodate these, and the magnetic circuit was bolted to it. Fig. 2(*a*) shows the view of the deflector seen from the electron gun; Fig. 2(*b*) shows the corresponding cross-section. The magnetic yoke is fabricated from $\frac{1}{2}$ in. Mumetal plate, to which are bolted the Mumetal cores of rectangular cross-section, which carry the energizing coils. Each pole-piece is held in position by a single bolt which is insulated from the yoke by mica sheet. All insulating material is screened electrostatically from the beam to prevent charging-up effects. The air gap of the magnets is quite small (3·0 mm), and, since the field required does not exceed 350 G, the excitation required in the air gap is also small. Care has to be taken with the iron circuit to ensure that the magnetomotive force drop across the iron is negligible compared with that associated with the air gap in order to preserve linear operation. An earlier design using soft iron instead of Mumetal proved unsatisfactory for this reason, especially for reflexion work where hysteresis and remanence effects become very noticeable.

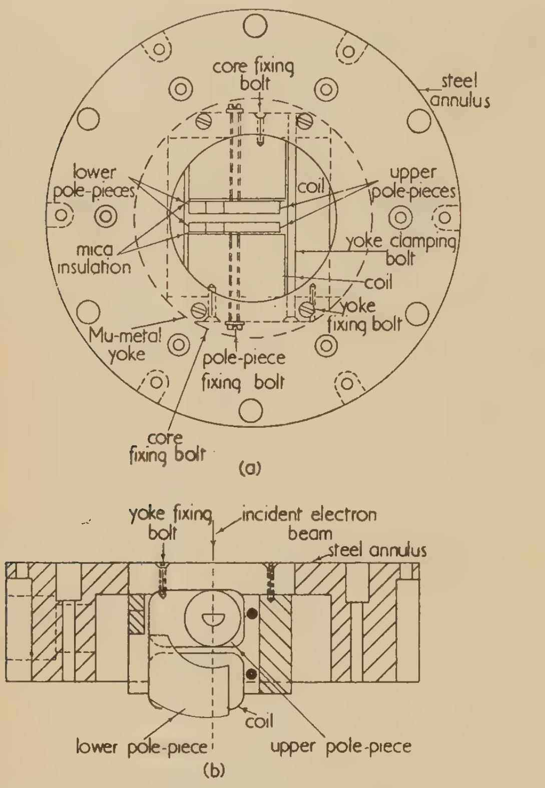

Fig. 2. (*a*) General assembly of deflector system. (*b*) Arrangement of the deflector plates

For transmission microscopy, the design of the deflector pole-pieces is relatively unimportant. Initially, rectangular pole-pieces were used instead of those shown in Fig. 2(*b*). These proved unsuitable for reflexion microscopy since they introduced astigmatism into the illuminating beam, leading to a considerable loss of intensity even for deflexions of a few degrees. Archard⁽¹⁾ pointed out that the reason for this is that the beam crosses the edge of the pole-pieces obliquely so that the fringing fields cause focusing perpendicular to the plane of the deflexion, leading to the formation of a line focus. The resulting minimum disk of confusion observed in the object plane is plotted in curve *B* of Fig. 3. This "obliquity" effect can be removed by curving the edges of the electrodes but, in general, the result is to cause electrons entering on parallel paths to travel different distances in the field, giving rise to a focusing effect *in* the plane of deflexion, and hence to an astigmatism of the opposite sign to the one described previously. This is shown in Fig. 3, curve *C*. By making the first pole-piece curved and the second rectangular, the astigmatisms should tend to cancel. This was foun be so for angles less than 5°; for greater angles, the c pensation is inadequate.

The arrangement finally adopted is shown in Fig. 2(*b*). this, the D-shaped gap, suggested by Archard, in the p pieces of the first deflector (filled by a copper block so as to disturb the electrostatic field) eliminates path differen effects, while the circular boundary eliminates "obliquit effects. Small residual path difference and obliquity effe at the exit surface of the second deflector cancel. T resulting astigmatism is shown in curve *A* of Fig. 3. Ast matism is negligible up to total tilt angles of 18°.

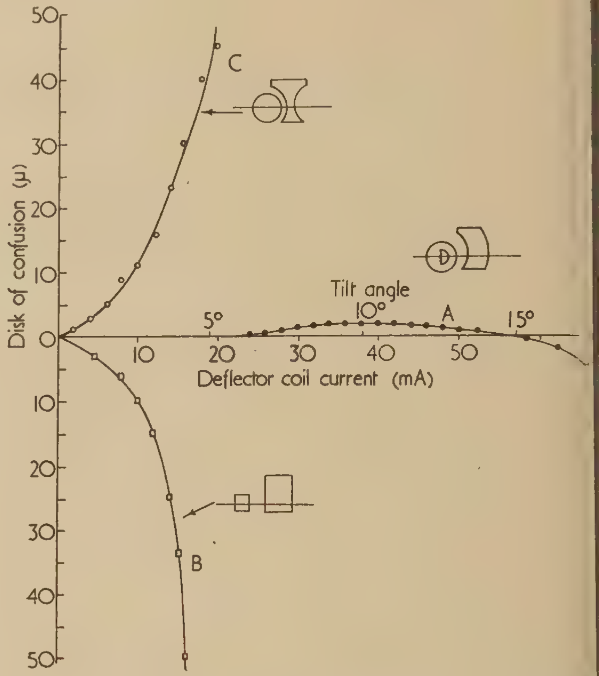

Fig. 3. Measured astigmatism of various deflecting systems

CONTROL CIRCUITS

A simple control circuit results if one upper and t opposite lower plate are employed to tilt the beam, and t other two plates to shift the beam. The circuit of the contr panel is shown in Fig. 4. The supply circuits are centr

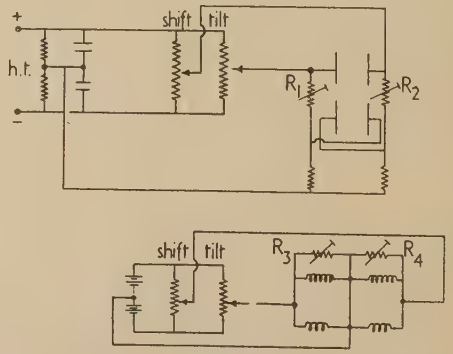

Fig. 4. Simple control circuits for alinement section

ped to allow deflexions either side of the mean without tching, Trimmer resistors R_1, R_2, R_3, R_4 enable indedent control of tilt and shift to be obtained. These stors are adjusted to eliminate shift of illumination as the control is operated. The compensation obtainable is quite perfect as the X tilt, when fully compensated to id all X shift, introduces a small movement in the Y ection, probably due to fringing fields between the plates. is simple system is satisfactory provided that only small salinements have to be compensated. If large voltages of same sign have to be applied to opposite deflector plates, mean potential of the plates rises with respect to the um potential and astigmatism is introduced. This is most ely to occur when using the double condenser lens to form illuminated spot of five microns or so. A symmetrical cuit was developed (Fig. 5), which is free from the above efects. The symmetrical circuit is, of course, more compliated than that of Fig. 3. All four plates carry the voltages or the tilt circuit and the shift is obtained by a superimposed alance voltage across one pair of plates, using the second nethod. The control circuit is complicated by these new equirements as the supply to the shift circuit must be insuated from earth and held at the tilt voltage applied to the ower plates.

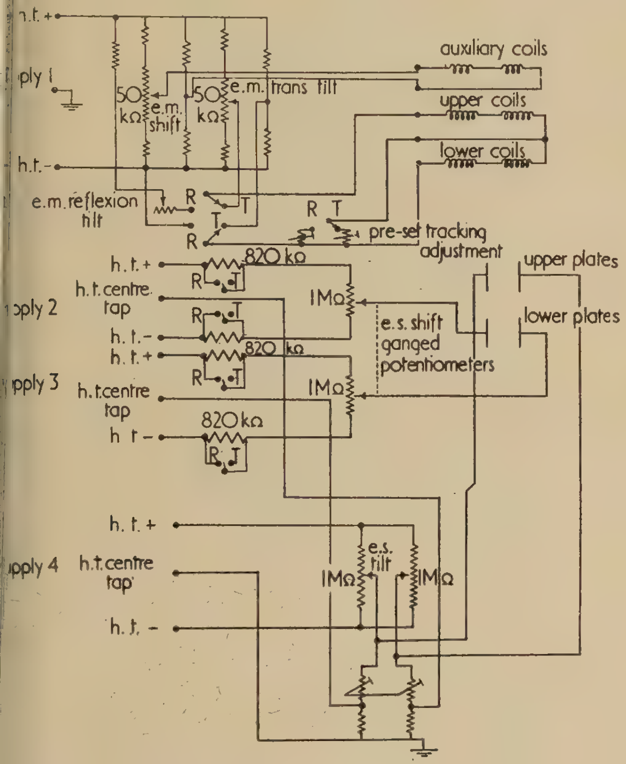

Fig. 5. Simplified diagram of final control circuit for alinement

Similarly, all four magnetizing coils are employed for the nagnetic tilt. In order to avoid complication of the supply ircuits, small auxiliary windings were added to the lower air of coils to provide a separate shift excitation.

For reflexion working, it was found necessary to provide ather more powerful electrostatic shift and tilt in the direction erpendicular to the main tilt than that needed for transnission working. This was achieved by shunting the 820 kΩ esistors which are in circuit for transmission operation. The magnetic tilt control is required to act in one direction only for reflexion work, and the centre tapping was therefore dispensed with. A separate trimmer was required for the compensated reflexion tilt, since the objective is working at long focal length, resulting in an appreciable change in l from 9 to 6·5 cm. The final circuits evolved are shown in Fig. 5. The ganged control rheostats were carefully matched in resistance.

RESULTS

Fig. 6 shows a micrograph of a copper surface obtained by reflexion microscopy using the new deflector stage. The total tilt of the electron beam is 18°; the angle of incidence θ_1 between the illuminating beam and the plane of the specimen is 8°, and the angle of viewing θ_2 between the plane of the specimen and the axis of the objective lens is 10°, the largest viewing angle that can be obtained with standard specimens in the present mechanical stage for reflexion.

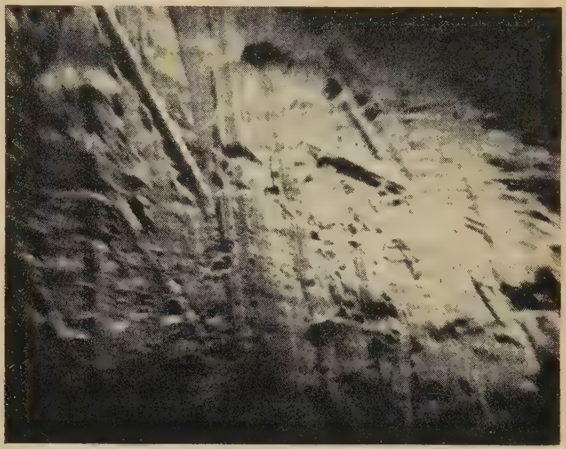

Fig. 6. Micrograph of a copper surface obtained by reflexion microscopy using the deflector stage (×1700) $\theta_1 = 8°$, $\theta_2 = 10°$.

CONCLUSION

A compact electron beam shift and tilt section has been designed to replace the normal mechanical system employed hitherto. This improves the mechanical stability of the illuminating system, provides more convenient alinement controls, and permits reflexion electron microscopy up to angles of beam tilt of about 20° without the necessity of moving the heavy illuminating system.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. G. K. Rickards and Mr. E. E. Pesterfield for their assistance with the experimental work, and Dr. J. S. Halliday for helpful discussion. They also wish to thank Dr. T. E. Allibone, Director of the Research Laboratory, for permission to publish this paper.

REFERENCE

(1) Archard, G. D., and Mulvey, T. *J. Sci. Instrum.*, **35**, p. 279 (1958).

The preparation of single-crystal ingots of silicon by the pulling technique

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The construction and operation of a laboratory furnace for preparing monocrystals of silicon by the pulling technique are described. The design allows for close observation of the growth front of the ingot during its preparation. It has been found possible to assess the quality of high-grade silicon, and also to obtain an indication of the concentration of dominant impurities responsible for the measured resistivity by comparison with computed distribution curves.

The design of a furnace for the preparation of monocrystalline ingots of silicon by the pulling technique presents more difficulties compared with the type of furnace required, for example, for the pulling of germanium crystals. Molten silicon (m.p. 1430° C) is chemically highly reactive and is easily contaminated by trace impurities. It is, therefore, of prime importance to eliminate as far as possible all obvious sources of contamination, i.e. contamination from the crucible containing the melt, from the atmosphere surrounding it and from metal parts which may outgas if allowed to warm up.

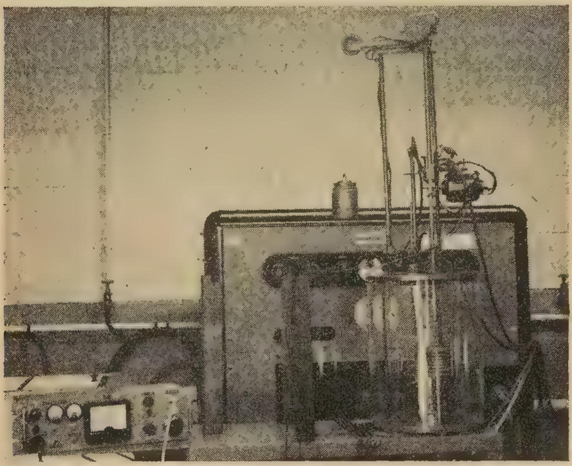

Fig. 1. General view of furnace for the preparation of monocrystalline ingots of silicon

The laboratory-type furnace to be described (Fig. 1) appears to fulfil this requirement adequately. Its main features are as follows:

(i) operating pressure can be reduced to 10^{-5} mm of mercury, with provision for admitting various gases if desired;

(ii) operating temperature up to 2000° C;

(iii) crucible capacity up to 30 g of molten silicon;

(iv) provision for adding new material to the crucible at operating temperature;

(v) the furnace was designed at a time (1952/53) when little information and experience was available on the growing of silicon crystals. A high degree of visibility was therefore given overriding importance, to allow for the closest possible observation of the growth front, i.e. of the interface of ingot and melt during crystal growth. It is, of course, realized that insistence on free observation along the surface of melt may lead to considerable heat loss from the in by radiation in the radial direction which mi adversely affect the structural perfection of growing ingot.(1) In a production furnace, wh such close observation is no longer required, it wo obviously be advantageous to minimize radial h losses, and this might be achieved, for instance, working with a deep crucible where radiation fr the ingot is minimized, the walls of the crucible be not much colder than the ingot itself;

(vi) the same consideration of gaining wider experience the growing of silicon crystals also determined choice of the thermal response time. A small therm capacity of the heated components, and consequen a fast response of the furnace, was aimed at in design, as this would allow rapid thermal adjustme to be made during growth. Thus, a fairly consta diameter of the cylindrical ingot could be maintain by making rapid adjustment of power input as so as any change in the diameter of the growing ing was observed. Once sufficient general experience gained from the operation of this furnace, the produ tion of a large number of identical ingots might w be undertaken with a furnace of quite different desig Thus, a large thermal mass might be aimed at minimize the effects of rapid fluctuations in pow supply, combined with automatic and accurate ter perature control to deal with any slow drift in t supply. Furthermore, the power input might pre-set—"programmed"—to deal with changes power required during the growth of the comple ingot as and when the level of the melt, i.e. the positio of the interface in the crucible, is lowered.

APPARATUS

The apparatus consists basically of a continuousl evacuated glass chamber in which all metal parts and th glass cylinder are water-cooled; heating power is provide by a 450 kc/s generator with a variable output up to 8 kW.

The work chamber is built up on a standard Metropolita Vickers vacuum evaporation plant which uses a type 03 oil diffusion pump backed by a type DR1 rotary pum The water-cooled base plate (Fig. 2) consists of a $\frac{1}{2}$ in. thic polished brass plate under which is fitted the flap valve wit a branch to an ionization gauge and the diffusion pum The copper tube r.f. power-leads pass through vacuum sea in a $\frac{1}{2}$ in. thick Perspex disk which is in turn bolted to th erside of the base plate. Also fitted through the base are cooling connectors to the r.f. concentrator (see w), a water-cooled pillar for holding the crucible and ectors for admitting gases.

ne wall of the work chamber consists of an inner hard-s (Pyrex) cylinder, 7 in. in diameter by $\frac{1}{4}$ in. wall thickness 15 in. long, which rests on a $\frac{1}{8}$ in. thick neoprene washer ssed into the base plate. Surrounding this is a Perspex der 12 in. in diameter and 14 in. long, which is clamped to a rubber ring fitted into a rebate in the base plate. nder operating conditions, the space between the two linders is filled with water flowing in at the bottom and to aste through a pipe terminating 2 in. from the top of the linder.

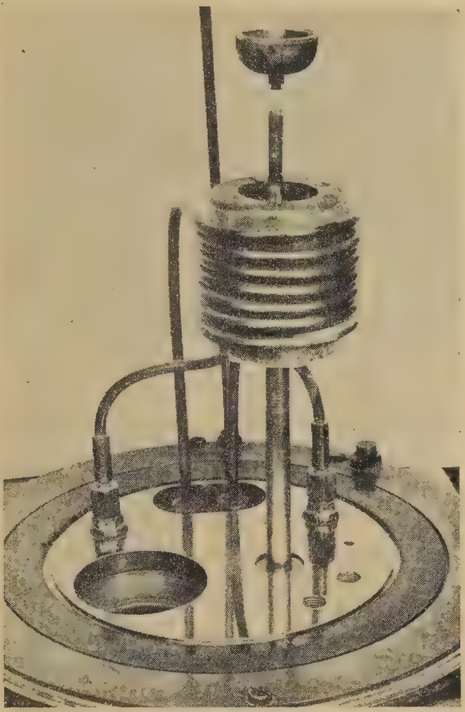

Fig. 2. Base plate and r.f. coil

The cover (Fig. 3) consists of an outer brass ring, with a recessed neoprene washer which rests on the glass cylinder, on which rests a brass plate fitted with a standard O-ring vacuum seal. This is sufficiently free under vacuum to move laterally or to rotate, and carries the seed holder with its raising and lowering mechanism and the feeder trough.

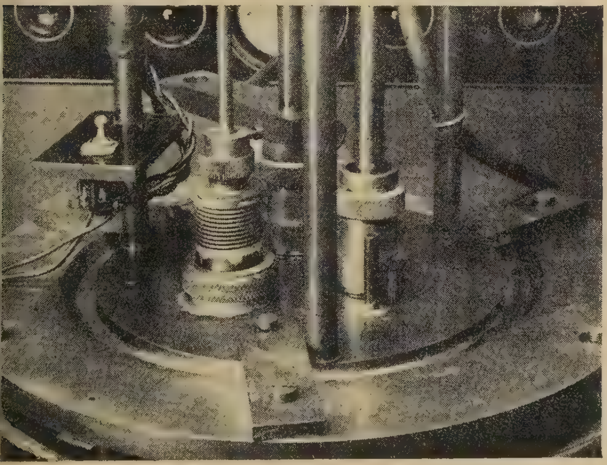

Fig. 3. Top plate

The rotating water-cooled seed-holder unit consists of a variable-speed motor with suitable gearing which turns a $\frac{1}{2}$ in. diameter stainless-steel seed-holder tube. The seal between this tube and the guide fitted to the movable top plate consists of a modified form of Wilson seal, lubricated with Apiezon B oil. The lower end of the tube contains a chuck consisting of a central hole $\frac{1}{4}$ in. deep and three equally spaced 4BA tapped radial holes. The whole unit is counterbalanced and is raised or lowered by a small variable-speed motor and gearbox, giving a speed range up to 4 mm/min.

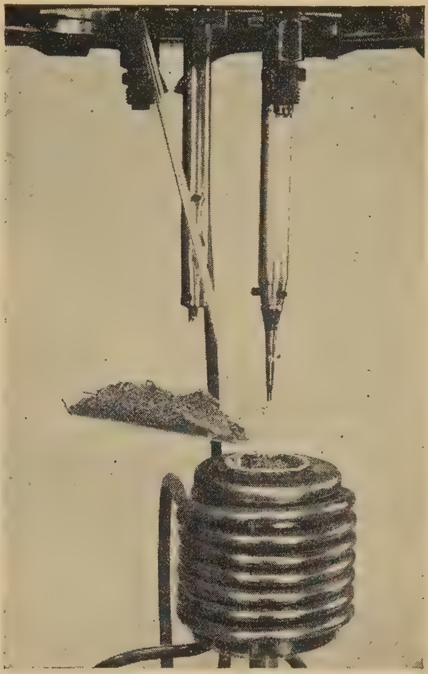

Fig. 4. Crucible and feeder trough assembly

The feeder trough (Fig. 4) is made of clear silica and is $1\frac{1}{4}$ in. wide and 3 in. long. This is held in a water-cooled holder which can be rotated manually to a position so that the raw material can be pushed into the crucible by means of a flexibly mounted clear silica rod operated from above the top plate.

The r.f. work coil consists of a six-turn $\frac{1}{4}$ in. outer diameter copper tube which surrounds the r.f. concentrator (Fig. 5). This is made up of a copper tube $2\frac{1}{2}$ in. outer diameter capped with a $\frac{1}{2}$ in. thick copper ring with a $1\frac{3}{8}$ in. hole in it. Copper tubing is wound against the inside wall of the cylinder, the whole assembly is brazed, and then a slot cut through one side. This concentrator acts as an r.f. power transformer having a one-turn secondary winding. Thus, the whole power of the primary coil of $2\frac{1}{2}$ in. axial length is concentrated into a region of only $\frac{1}{2}$ in. axial depth, which can then be effectively coupled into the graphite susceptor. The cup-shaped r.f. susceptor is machined from high-purity graphite bar, and rests on a small-diameter transparent silica tube fixed to a water-cooled pillar passing through the base plate. The susceptor is machined in such a manner that the transparent silica crucible used rests only on its rim. The four equally-spaced slots cause the induced r.f. current to heat the middle of the susceptor about 100° C higher than the rim at operating temperature.

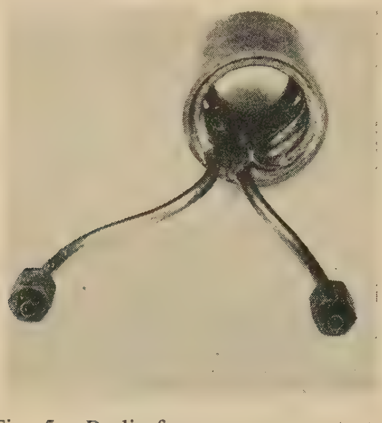

Fig. 5. Radio-frequency concentrator

The crucibles used are of squat form, glazed transparent Vitreosil. The upper part of the wall of the crucible is cut off to suit the amount of material being used.

PREPARATION OF APPARATUS FOR GROWING SINGLE-CRYSTAL INGOTS

Cleaning of the seed, crucible and trough is carried out using AnalaR reagents, polythene containers and tweezers, and deionized water. A chemical etch is used, made up of equal volumes of hydrofluoric acid and nitric acid, and washing is carried out in three rinses of deionized water. The raw silicon is not cleaned, except where the material looks obviously dirty. It has been found impracticable to clean powdered or needle-like material.

Single-crystal seeds (Fig. 6), about 5 cm long by 3 mm diameter at the growing tip, increasing to about 1 cm diameter at the end of attachment to the seed holder, have been found satisfactory. Anything shorter or smaller in diameter at the end of attachment was found to be unsatisfactory owing to evaporated deposits from the melt which formed on the end of the water-cooled seed holder. This deposit gradually built up in thickness and then dropped into the melt, sometimes causing a growing ingot to go polycrystalline. One seed has been found satisfactory for preparing up to fifty ingots, and its life is limited only by the gradual thinning down due to the chemical etch cleaning process. Seeds are normally oriented for growth along [100] or [1 direction.

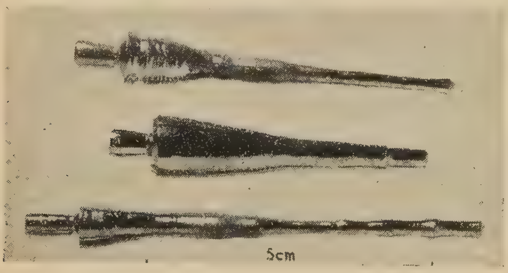

Fig. 6. Single-crystal seeds

The seed is clamped by means of three grub screws in seed holder; a small amount of silicon is put into the cruci and the remainder into the feeder trough. The crucible a susceptor are then positioned in the concentrator so that t top of the susceptor is flush with the top of the concentrat The apparatus is then assembled, with the seed over t centre of the crucible, and pumped to less than 5×10^{-5} m of mercury, the residual pressure being measured with ionization gauge.

With the arrangement of work coil, concentrator a susceptor used, about 5 kW r.f. power is required to m the initial charge. Owing to the highly localized source heat—the small graphite susceptor—the melting down of t charge can be troublesome, especially if this is in the form fine powder or of fine crystalline needles. There is the dang that only the lowest layer of the charge will melt and subs quently lose thermal contact with the remainder of t charge, which then tends to sinter together to form a "bridge This can only be melted down by heating the susceptor an crucible to an excessively high temperature. The brid formation can be prevented by using larger lumps "densified" material as the charge, or alternatively by havi only one such lump in the crucible to start with; this is readil melted down and the remainder of the charge can then gradually fed into the melt from the trough of transpare silica previously described. About 3 kW r.f. power required to maintain a full crucible at operating temperatu The vacuum can be maintained below 2×10^{-5} mm mercury.

TECHNIQUE FOR PULLING SINGLE-CRYSTAL INGOTS

Dipping seed (preparation in high vacuum). The see holder is rotated at a constant speed of 1 rev/2 s and th temperature of the melt is adjusted so that, when the seed lowered to touch the melt, wetting takes place and the soli liquid interface reaches a stationary level (Fig. 7). Pullin is started at a rate of 2 mm/min, and the r.f. power is adjuste so that the new growth is the same diameter as the seed It is during this stage of growth that examination of the symmetry of the incipient crystal facets reveals whether the new growth is entirely monocrystalline. If this is not so it is a simple matter to lower the seed to melt off the new growth and start again.

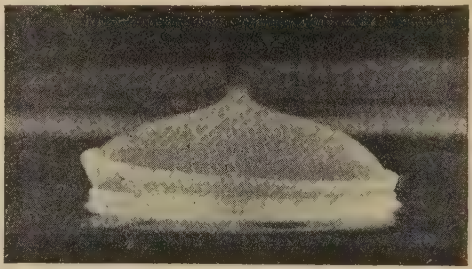

Fig. 7. Single-crystal seed in contact with melt

Controlling the ingot diameter. The diameter of the solid-liquid interface, and hence of the growing ingot, is now gradually increased while pulling (Fig. 8) by lowering the r.f. power. When the desired diameter is reached, the r.f. power is slowly raised to maintain that diameter constant. Small ver adjustments are then made as the ingot grows in gth to compensate for increased heat radiation from the d, decreasing volume of the melt and for direct r.f. power pling into the solid ingot. As the level of the liquid drops, ulls away from the wall of the crucible owing to its high face tension, and its surface changes from near-horizontal the start to vertical towards the later stages of growth. e liquid then tends to wander in the crucible and may even ig fast to one side. With the ingot rotating in the melt, growth process is then badly disturbed, and the lower ts of the ingot are much less perfect than the almost indrical part grown under relatively steady conditions.

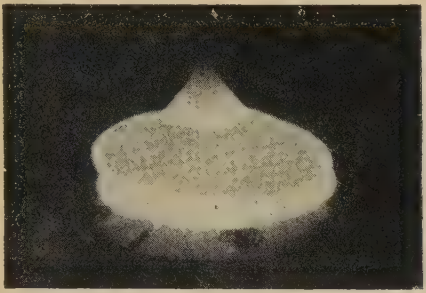

Fig. 8. Crystal growth with increasing diameter. Growth direction [100]. Two facets can be seen at the solid/liquid boundary

As the solid-liquid interface approaches the bottom of the ucible, the pulling rate is increased to 4 mm/min, and then ie crucible is lowered quickly to cause the remaining small uantity of melt to break contact. It is thus feasible to pull p the last drop of the melt, leaving the crucible absolutely ear. In this way it becomes possible to re-use one crucible or several runs, a procedure which might have certain dvantages (see below).

Cooling the ingot. The completed ingot is maintained at a emperature of 1200 to 1300° C, heated partly by direct r.f. ower coupling and partly by irradiation from the susceptor. low cooling is ensured by raising the ingot at 4 mm/min way from the r.f. field and from the hot susceptor. A typical ime schedule for the preparation of a medium-sized ingot about 20 g) is as follows.

Typical time schedule for the preparation of a medium-sized ingot

Time (min)	*Power setting (kW)*	*Condition*
0	5	Small initial charge in crucible.
3	5	Initial charge melted. Extra material fed in from trough.
7	3	Seed lowered into contact with melt.
8	3	Pulling started at 2 mm/min.
10	2½	Single-crystal growth verified by observation of incipient facets; increase in diameter started.
13	2½ (increased slowly)	Increase in diameter stopped; solid-liquid interface raised.
16	3 to 3½	Constant-diameter growth established.
27	3 to 3½	Last drop of melt pulled up from crucible; ingot raised at 4 mm/min.
40	Power off	

ELECTRICAL MEASUREMENTS OF INGOTS

The general shape of the ingots is shown in Fig. 9.

Electrical resistivity measurements are carried out using an apparatus which has four probes in line, spaced 1 mm apart.(2) To verify the polarity of the ingot, where this is in doubt, the sign of the thermoelectric power is checked with a heated point probe. These measurements are made either along the surface of the ingot or along a longitudinally cut surface, usually at 2 mm intervals along the length of an ingot.

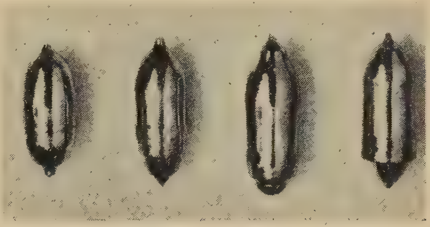

Fig. 9. Single-crystal ingots of silicon

EXPERIMENTAL RESULTS

Over a period of time, ingots have been prepared using material from a number of different sources; whenever possible at least two ingots have been prepared from a given sample. The resistivity values for these ingots have varied from less than ten to many hundreds of ohm centimetres, whilst with the availability of improved grades of silicon, the range has generally been from 100 to 500 Ω cm, *p*-type.

The distribution of resistivity along an ingot can provide useful information on the residual impurities, and under certain conditions may enable one to recognize whether compensation of donor and acceptor impurities has taken place. Furthermore, by making use of the segregation coefficients, the values of which are known for the various impurities involved, an estimate can be made of the concentration of these impurities in the melt. Thus, resistivity measurements at close intervals along the ingot can form the basis of a rapid appraisal of the material and also provide some information on any contamination during the pulling process.

During the growth of an ingot from the melt, there exist at least three processes which might affect the final distribution of impurities along the ingot:

(i) segregation of impurities from the melt;
(ii) evaporation of impurities from the melt;
(iii) addition of impurities to the melt from the crucible and other contaminating sources.

Bradshaw and Mlavsky(3) have shown that the most significant ionizing impurities remaining in liquid silicon when held under vacuum are boron, aluminium and phosphorus. Copper and iron also have slow evaporation rates, but their segregation coefficients are very small. Thus, copper, iron and other relatively non-volatile impurities might all be present, but only aluminium amongst the acceptor impurities would be in sufficient quantity to contribute significantly to the final resistivity profile, whilst most of the Group V impurities (donors), apart from phosphorus, are likely to be evaporated from the melt to a large extent. It may then be assumed that the resistivity distribution will mainly be affected by the relative concentration of the three elements phosphorus, boron and aluminium.

In Fig. 10 are shown the computed equilibrium profiles resulting from any two of these three elements being present in various proportions at the seed end of the ingot. The distributions were calculated from the expression:

$$c = kC_1(1 - g)^{k-1}$$

where c is the impurity concentration in the solid, C_1 the initial impurity concentration in the melt, g the volume fraction of the ingot solidified, k the segregation coefficient, i.e. the equilibrium ratio of impurity concentrations in solid and liquid at the interface. (The equilibrium value of k has been used throughout, no allowance being made for the possibility of its dependence on additional factors such as rate of pulling and rotation, etc.) The values used for t computation are: $k = 0{\cdot}9$ for boron, $k = 0{\cdot}35$ for pho phorus, and $k \ll 1$ for aluminium. Other non-volat acceptor impurities with $k \ll 1$ will give similar results b with, of course, numerically different concentration rati The distribution curves have been adjusted to unit resistiv at the start, and apply to an ingot which is p-type at its se end. The curves are applicable in the range $|N_D - N$ $< 10^{17}$ atoms/cm^3.

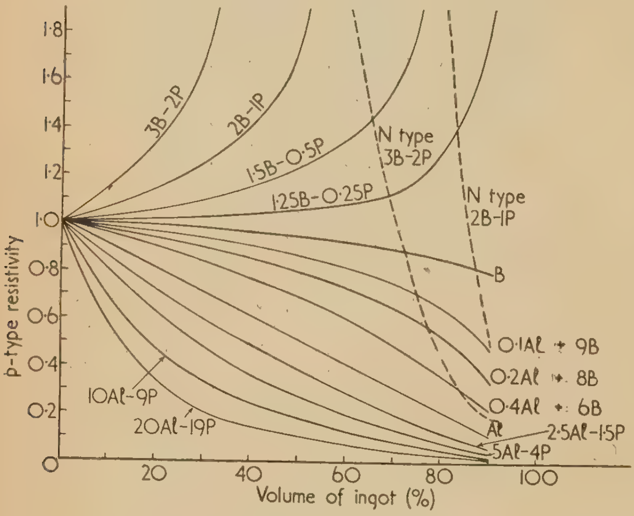

Fig. 10. Computed equilibrium resistivity profiles for any pair of the impurities Al, B and P present in various proportions at seed end of ingot

Most, if not all, the resistivity profiles measured on t ingots pulled during these experiments could be fitted approx mately to one or other of the computed curves, as is show in the following examples. In each case, the comput resistivity distribution has been corrected for the shape the ingot deviating from that of a perfect cylinder. Fig. shows a typical distribution obtained on an ingot of reaso ably constant diameter on which has been superimposed th computed resistivity distribution due to an acceptor with small segregation coefficient, possibly aluminium. A shown is the distribution due to 0·4 parts aluminium ar 0·6 parts boron. The scatter of the measured values mak it difficult to fit them exactly to either distribution, but th indication is that any residual donor impurities which ma be present in the ingot are too few in number to cau noticeable compensation.

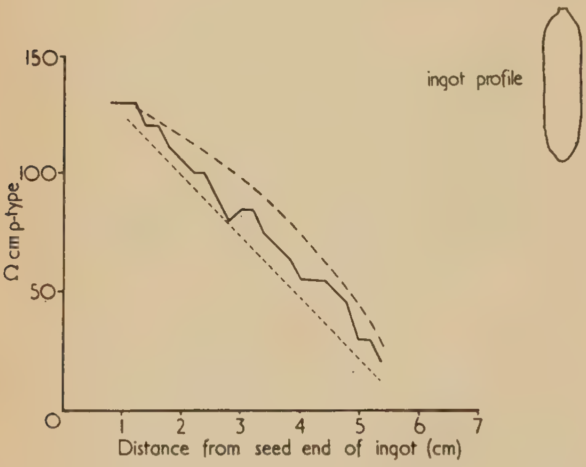

Fig. 11. Comparison of experimental and computed resistivity profiles

—— = experimental distribution; – – – – = computed distribution due to acceptor with small segregation coefficient; — — — = computed distribution due to 0·4 parts aluminium and 0·6 parts boron present at seed end of ingot.

Fig. 12 shows another case where the computed distr bution, due to twenty parts aluminium and nineteen parts phosphorus present at the start of the ingot, has been super- imposed on the experimental curve. The good fit obtaine indicates that the high starting resistivity was, in this case very largely due to close balancing of donor and acceptor impurities.

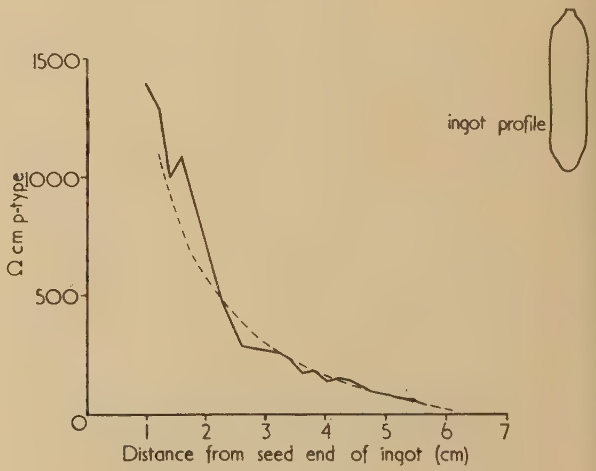

Fig. 12. Comparison of experimental and computed resistivity profiles

—— = experimental distribution; – – – = computed distribution due to 20 parts aluminium and 19 parts phosphorus at seed end of ingot.

Fig. 13 shows a case where the experimental distribution is largely determined by the boron content, with a small degree of compensation due to phosphorus. It is apparent that with this form of distribution, it is not necessary to correct the computed distribution to allow for changes in ingot shape, in order to form an idea of the degree of impurity compensation which has taken place.

Fig. 14 shows an example of the repeatability of results

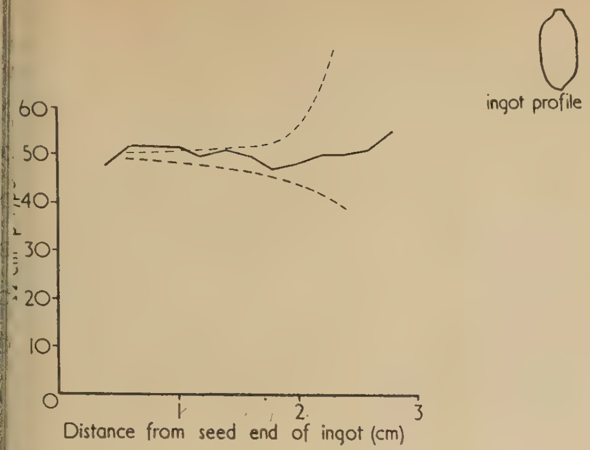

Fig. 13. Comparison of experimental and computed resistivity profiles

—— = experimental distribution; – – – = computed distribution due to 1·25 parts boron and 0·25 parts phosphorus present at seed end of ingot. — — — computed distribution due to boron.

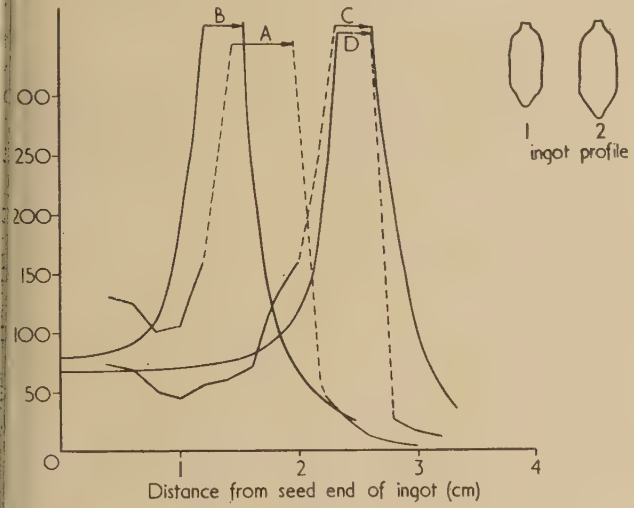

Fig. 14. Comparison of experimental and computed resistivity profiles

Ingot 1: curve *A*, experimental distribution; curve *B*, computed distribution due to 3 parts boron and 2 parts phosphorus. Ingot 2: curve *C*, experimental distribution; curve *D*, computed distribution due to 2 parts boron and 1 part phosphorus. Both ingots are *p*-type near the seed and *n*-type near tail end.

obtained on two ingots prepared from the same batch of raw material. The result suggests that, in each case, boron and phosphorus are the dominant impurities at the start of the ingot; allowing for the higher segregation coefficient of boron compared to that of phosphorus, it may be inferred that the raw material itself is probably dominantly *n*-type and the effect due to acceptor impurities with a small segregation coefficient is negligible.

Another factor which can affect the distribution of impurities along an ingot is contamination of the melt by the crucible material. To check this point, in one particular experiment pulling was stopped for fifteen minutes before the second half was grown. Analysis of the resistivity profile indicated that in this particular case contamination from the crucible caused an increase of free current carriers of no more than about 10^{13} per cm^3.

CONCLUSIONS

When using high-grade silicon, as is available at present, the pulling of ingots in vacuum from an undoped melt is a method of limiting the dominant ionizing impurities to boron, phosphorus and aluminium. The remaining donor impurities tend to boil off, resulting in ingots with predominantly *p*-type characteristics.

The method of analysis described is empirical but indicates when high resistivity is due to balancing of donor and acceptor impurities. It also enables one to draw some conclusion on the concentrations of certain impurities in the raw material.

In experiments where a crucible has been used again without further cleaning treatment, slightly higher resistivity results have been achieved. If other parts of the apparatus are a source of contamination, it can be assumed that they remain constant, and the apparatus is still valuable for preparing ingots on which electrical measurements can be made for the purpose of comparing the purity of different sources of raw material.

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REFERENCES

(1) Billig, E. *Proc. Roy. Soc., A*, **235**, p. 37 (1956).
(2) Gasson, D. B. *J. Sci. Instrum.*, **33**, p. 85 (1956).
(3) Bradshaw, S. E., and Mlavsky, A. I. *J. Electronics*, **2**, (2), p. 134 (1956).

The sensitivity of low-frequency valve amplifiers for electromyography

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An analysis of the required sensitivity of electromyograph amplifiers is given in terms of the source impedance. Possible sources of noise in low-frequency amplifiers are discussed and estimates of their magnitudes made on the basis of previous published figures. An account is given of an experimental comparison between valve types, and an investigation of the effect of operating conditions; the noise depends on both the grid bias and the anode current. Spectral analyses are given of the noise from selected valves in the range 2 to 16 000 c/s. Persistent selection and good fortune have brought to light a pair of valves with a noise level lower than any previously reported in this frequency range (as far as the author is aware). Finally it is shown how, under certain conditions, the noise performance can be improved by means of an input transformer.

1. INTRODUCTION

The sensitivity of measurements of the electrical potential differences produced by the human body is usually determined by the noise generated in the first stage of the amplifier. In a typical equipment covering a frequency range from 10 to 2000 c/s the amplifier noise has a magnitude of about 4 μV (r.m.s.), corresponding to about 20 μV (peak-to-peak), which must be compared with 10 μV for the smallest signals which have to be detected.$^{(1)}$

The *ultimate* sensitivity of the system depends, of course, upon the electrical noise generated by the source itself; the smallest conceivable value of this source noise is the thermal noise attributable to the resistive component of the source impedance. In electromyography, metal surface electrodes are attached to the skin over the muscle, the electrical activity of which is to be studied, or needle electrodes are inserted into the muscle, so that the source consists of the electrodes in series with the tissues. The impedance of this system can conveniently be divided into a part associated with polarization at the interfaces between the metal electrodes and the tissue electrolytes, and a part associated with the tissues themselves. Each of these impedances contains a capacitative component as well as a resistive component, both of which decrease with increasing frequency. At any frequency the magnitude of the total equivalent series reactance of the source impedance is of the same order as that of the equivalent series resistance. To avoid distortion the input impedance of the amplifier must be made large compared with the largest value of the source impedance likely to be encountered in the frequency band of interest. To achieve the ultimate sensitivity the noise level of the amplifier, expressed in terms of its equivalent noise resistance averaged over the band, must be smaller than the smallest source resistance likely to be encountered, also averaged over the band. [$R_{average} = \int_{f_1}^{f_2} \frac{R(f)df}{\Delta f}$, where $R(f)$ is the resistance at f c/s, and Δf is the band width.]

The frequency range for electromyography is taken here to be 10 to 2000 c/s. (For some clinical investigations a higher upper limit of 5000 c/s is employed, and for studies of muscle function a lower upper limit of, say, 600 c/s is permissible.$^{(2)}$) If needle electrodes are used the source resistance at 10 c/s may be as high as 50 kΩ, but with surface electrodes 1 cm in diameter on suitably prepared skin the value is usually lower and a representative figure for $R_{average}$ is 5 kΩ. An amplifier suitable for both types of electrode must therefore have an input impedance high compared w 50 kΩ and an equivalent noise resistance lower than 5 k

In special cases the author has found it useful to redu the source impedance with surface electrodes still further rubbing away most of the horny layer of the skin. T results in a value for $R_{average}$ of about 500 Ω, and gives ri to a requirement for a second type of amplifier with an inp impedance of, say, 10 000 Ω and an equivalent noise resistan less than 500 Ω.

The difficulty of satisfying these requirements led t author to make a thorough analysis, based on the results previous workers, of the possible sources of noise in lo frequency amplifiers (Section 3) and to undertake the expe mental investigations described in Sections 4 to 6. Althou the problem is described in terms of the requirements electromyography, similar principles can be applied electroencephalography.

2. THE PRE-AMPLIFIER AND THE METHODS EMPLOYED FOR MEASURING THE NOISE

In order to make numerical estimates of the expect magnitudes of the various sources of amplifier noise it w necessary to start with a typical pre-amplifier circuit (Fig. A biological pre-amplifier must have a balanced input sta to reduce interference picked up from mains supplies by th input leads, and in this case it was convenient for the secon stage to act as a "compressor" providing a single-sided ou put to feed the main amplifier. Analyses of balanced stag have been given by Parnum,$^{(3)}$ Offner$^{(4)}$ and Gray,$^{(5)}$ and the compressor stage by Toennies.$^{(6)}$ In considering th noise generated by the first stage we can treat it as a simp

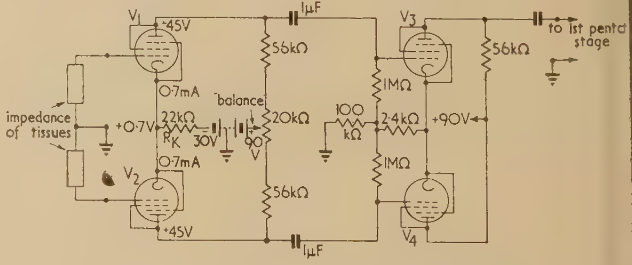

Fig. 1. Electromyograph pre-amplifier

All valves type EF37A.
All resistors wire wound.

ge with no cathode load, remembering that the value of noise calculated for one valve will have to be multiplied $\sqrt{2}$. This was confirmed experimentally (Section 5).

The upper and lower half-power points of the frequency ponse chosen were 2300 and 10 c/s, and the equivalent ndwidth was 3000 c/s.

The total wide band amplifier noise was measured by :ing the peak-to-peak amplitude on a cathode-ray tube. is cannot be precisely defined, since, in principle, if one its long enough one may obtain a peak of any size, but was found that with practice a given observer obtained nsistent results, and comparison with a thermocouple :ter showed that the ratio r.m.s. to peak-to-peak was 0·20 within a few per cent. This ratio held only for wide band ise, i.e. for a band the width of which was comparable th the centre frequency. The method was not used for rrow band noise, the waveform of which looks rather like amplitude-modulated carrier and for which it was found ore difficult to obtain consistent readings for the peak-to-ak amplitude.

For measurements on the spectrum of the noise in the nge 20 to 16000 c/s a Muirhead–Pametrada wave analyser as employed; the bandwidth was 4·5% of the centre equency. For measurements at frequencies between 2 and) c/s a Muirhead low frequency modulator unit was used conjunction with the analyser; this system gave a band c/s wide. The analyser meter was calibrated by comparison ith a thermocouple meter. The accuracy of absolute ieasurements of the root mean square voltage in unit band-idth was estimated to be rather better than ±10%.

3. THE POSSIBLE SOURCES OF NOISE AND ESTIMATES OF THEIR MAGNITUDE

3.1 *Thermal noise in metallic conductors.* This follows ie law $\overline{\Delta V^2} = 4kTR\delta f$(7–10) for the range of frequencies of nterest here, where k = Boltzmann's constant, T = absolute emperature, R = resistance of conductor, and f = frequency. 'his can be reduced to V (r.m.s.) $= 1{\cdot}28 \times 10^{-10}\sqrt{R\delta f}$ V at room temperature of 20° C. As is implied by the formula, he noise is "white," i.e. it is uniformly distributed throughout he spectrum. In the system of Fig. 1 thermal noise can rise in the source, the resistive component of the input mpedance and in the circuit resistors. The source impedance ias already been discussed in Section 1; it is lower than and, rom the noise-generating point of view, in parallel with, the nput impedance, so that the latter can be neglected. The ignificant resistors are the anode load of the first stage and he grid leak of the second, which are effectively in parallel with the anode resistance of the first stage. In this case the equivalent noise resistance is about 20 kΩ which produces approximately $1{\cdot}8 \times 10^{-8}\sqrt{\delta f}$ V as (r.m.s.) to be handed on to the second stage. The noise referred to the input is obtained by dividing this by the gain of the first stage, which is 20, to give $0{\cdot}9 \times 10^{-9}\sqrt{\delta f}$ V. There are two such generators in the double input stage, so the equivalent noise input for thermal noise is $\sqrt{2} \times 0{\cdot}9 \times 10^{-9}\sqrt{\delta f}$ V, or $1{\cdot}3\sqrt{\delta f}$ mμV (r.m.s.). The equivalent noise resistance is about 100 Ω.

The anode load of the second stage will, of course, contribute noise in the same way, but this will be effectively reduced by the gain of the second stage and can be neglected.

3.2 *Anode shot noise.* Under saturated conditions the fluctuations in anode current are given by $\overline{\Delta I_a^2} = 2eI_a\delta f$(10, 11) where e = electronic charge, and I_a = mean anode current. Again, the noise is "white." Under space charge limited conditions the fluctuations are reduced and the above expression becomes $\overline{\Delta I_a^2} = F^2(2eI_a\delta f)$; F^2 is called the "space charge smoothing factor" and is of the order of 0·1 for low-power triodes. Theoretical treatments have been given by Schottky and Spenke,(12) Schottky(13) and North.(14) A useful working approximation given by Gillespie(15) is $F^2 = 0{\cdot}12/I_a$ gm where g_m is the mutual conductance of the valve. This gives $\overline{\Delta I_a^2} = 3{\cdot}8 \times 10^{-20}\, g_m\delta f$ A^2. To apply this formula to the input stage of the amplifier it is necessary to calculate the voltage fluctuation developed across the load resistance and anode resistance in parallel, and divide by the stage gain to obtain the equivalent input noise. Allowing for both valves of the pair, we find $6{\cdot}5\sqrt{\delta f}$ mμV (r.m.s.). The equivalent noise resistance is about 2·5 kΩ. As in the case of thermal noise, the contributions of later stages can be neglected.

3.3 *Grid shot noise.* This is similar to anode shot noise in origin, except that the grid may collect positive ions and electrons simultaneously, so that the mean square current fluctuation is

$$\overline{\Delta I_g^2} = 2e(I_g^+ + I_g^+)\delta f$$

It appears that grid shot noise is not modified by space charge.(16) Gillespie(15) measured the grid currents of a large number of triode-connected type EF37A valves. It is probable that under the operating conditions of the circuit of Fig. 1 the grid current was of the order of 10^{-11} A, representing the difference between an ionic current of (say) 5×10^{-11} A and an electronic current of 6×10^{-11} A. To obtain a probable upper limit to the grid shot noise we can put $I_g^+ = I_g^- = 10^{-10}$. Then $\overline{\Delta I_g^2} = 64 \times 10^{-30}\ \delta f$ A^2. The mean square voltage fluctuation developed at the input terminals depends on the source impedance. Taking the largest value found for needle electrodes, 50 kΩ, we find $\overline{\Delta V^2} = 16 \times 10^{-20}\ \delta f$ V^2, giving noise for two valves equal to $0{\cdot}56\sqrt{\delta f}$ mμV (r.m.s.). The equivalent noise resistance is 20 Ω. This figure, although a pessimistic estimate, is much smaller than the anode shot contribution calculated above, and also negligible compared with the thermal noise of a 50 kΩ resistor ($30\sqrt{\delta f}$ mμV), and it was concluded that the grid shot noise was negligible. This was confirmed experimentally. The output of the amplifier was taken to the analyser and a metallic resistor of 0·5 MΩ was connected from each input terminal to earth. The noise output (V_{total}) was measured in a narrow band centred at 15 c/s, and then the amplifier contribution with the resistors short-circuited ($V_{\text{ampl.}}$). The contribution of the resistors V_R was obtained by using the expression

$$V_R^2 = (V_{\text{total}})^2 - (V_{\text{ampl.}})^2$$

The result agreed within a few per cent with the expected value of the thermal noise of a 1 MΩ resistor at room temperature. The measured value would have been greater than the theoretical value if grid shot noise had been significant.

3.4 *Flicker noise.* Excessive noise at low frequencies was discovered by Johnson(17) and the term "flicker" was coined by Schottky.(18) Johnson found that the noise in diodes with oxide-coated cathodes was much greater than the anode shot noise at low frequencies, e.g. ten to twenty times at 1 kc/s. He interpreted the effect in terms of changes of emission involving local areas of the cathode. Under space charge limited conditions the noise was smoothed in the same way as anode shot noise. Tomlinson(19) reported that the smoothing was even greater for flicker noise. Its spectrum follows approximately the "1/f law," rising rapidly with decreasing frequency. For low-power amplifying valves with oxide-coated cathodes the flicker noise referred to the grid is given approximately in the range 1 c/s to 50 kc/s by

$$\overline{\Delta V^2} = (10^{-13}/f)\delta f \text{ V}^2 \text{ (Gillespie}^{(15)}\text{)}$$

This author pointed out that the formula gives only an indication of the value to be expected, since the flicker noise varies widely from one type of tube to another and from one individual to another of a given type. Taking Gillespie's formula, we obtain the following values for a two-valve input stage; 140 mμV (r.m.s.) per √1 c/s at 10 c/s and 14 mμV per √1 c/s at 1000 c/s. The flicker noise falls to the order of shot noise at frequencies around 10 kc/s.

3.5 *Partition noise.* If a pentode amplifier is used a further source of noise must be considered. North$^{(14)}$ developed a theory showing how the division or partition of the total tube current between the collector electrodes decreases the smoothing effect of the space charge. For shot noise the increase in equivalent noise input is of the order of three times,$^{(20)}$ but for flicker noise only about one and a half times.$^{(21)}$ Most authors recommend using triode stages to avoid partition noise. This point was investigated experimentally and no appreciable difference was found between triode- and pentode-connected EF37A valves (Section 5).

3.6 *Current noise in composition resistors.* Composition resistors when carrying a steady current produce far more noise than metallic resistors. Harris$^{(22)}$ showed that the mean square noise voltage was given by an equation of the form $\overline{\Delta V^2} = KI^x/f^y$ where I is the current, K a constant, and x approximately 2 and y approximately 1. In a 1 MΩ carbon resistor carrying 50 μA he found that the noise was about 10 μV per √1 c/s at 10 c/s and 1 μV per √1 c/s at 1000 c/s. This implies that wire-wound resistors must be used in the early stages of low-frequency amplifiers. The relative importance of this source of noise was tested in the circuit of Fig. 1 by replacing the wire-wound resistors by composition ones; the noise increased from 4 μV (for selected tubes) to about 30 μV (peak-to-peak). Most of this extra noise came from the current-carrying anode loads of the first stage.

It is clear from these figures, summarized in Table 1, that the main factor limiting the sensitivity of an amplifier of this type is flicker noise. A rough estimate for the total noise in the frequency range covered by the amplifier can be obtained by integrating Gillespie's expression

Table 1. *Summary of noise sources to be expected in the amplifier of Fig.* 1

Source	*Estimated magnitude*	
	[mμV (r.m.s.) per √1 c/s]	*Equivalent noise resistance (kΩ)*
Thermal resistance noise	1·3	0·1
Anode shot noise	6·5	2·5
Grid shot noise	0·56	0·02
Flicker noise	140 at 10 c/s 14 at 1 kc/s	1200 at 10 c/s 12 at 1 kc/s

$$\overline{\Delta V^2} = \int_{f_1}^{f_2} (10^{-13}/f)df = 10^{-13} \log_e \frac{f_2}{f_1}$$

for the equivalent band defined by the half-power points f_1 and f_2, which are 10 and 2300 c/s respectively. This gave 77×10^{-14} V^2. However, this method of calculation is suspect because the value obtained depends so strongly upo the figure chosen for the lower frequency limit; a mo rigorous method is to take $\int_0^\infty \overline{\Delta V^2}(f)p^2(f)df$, where $p^2(f)$ the square of the relative voltage response of the amplifie normalized to unity in the centre of the pass band, an $\overline{\Delta V^2}(f) = 10^{-13}/f$. This integration was carried out graphically and yielded the figure 72×10^{-14} V^2. The flicker nois for two valves is then found to be 1·2 μV (r.m.s.), or abou 6 μV (peak-to-peak). The equivalent noise resistance about 40 kΩ for the band covered by the system.

The measured value of the amplifier noise was found t be considerably greater than this, namely 20 μV (peak-to-peak), for the first pair of valves that came to hand. It wa therefore necessary to investigate further the possibility o reducing the noise by comparing valve types and individua valves, and by studying the effect of changing the operatin conditions.

4. EXPERIMENTAL COMPARISON BETWEEN VALVE TYPES AND INDIVIDUAL VALVES

The valves were inserted in pairs into the input circuit o the amplifier of Fig. 1. The wide band amplifier noise output with the input grids earthed was measured by the peak-to-peak excursion on an oscilloscope as explained i Section 2. By pairing valves in different ways it was possible to find three good ones, any two of which gave the same noise. The noise from each of these three must then have been the same, and was found by dividing the output with two valves by √2. One of these valves was then paired with all the others in turn so that the contribution of each coul be found.

The frequency response of the system was reduced at the higher frequencies, after preliminary measurements of the spectrum of the noise had indicated as expected that the flicker noise was predominant at low frequencies; it was anticipated that differences between valves would be mainly found in the low-frequency range rather than at higher frequencies where shot noise became important. The half-power points were 10 and 300 c/s, and the equivalent bandwidth 400 c/s.

Four different valve types were compared, chosen on the recommendation of the manufacturer or of other workers experienced in the subject. The results are shown in Table 2. The approximate operating conditions in the circuit are recorded in Table 3. Subsequent measurements on the variation of noise with grid bias showed that the Z729 valves had been tested at too low a bias; the noise at the optimum bias might be expected to be less by about 30%. Allowing for this, it is clear that the EF37A valve was the best of the types tested. It should be added in fairness to the Z729 and 6BR7 valves that these two types were found to be far less microphonic than the EF37A, having a more rigid electrode structure. Furthermore the Z729 valves were remarkably consistent.

The mutual conductance (g_m) and anode current (I_a) were measured for each of the type EF37A and EF40 valves under approximately the same operating conditions as those of the amplifier input stage, to find out if there was any obvious relationship between these parameters and the valve noise. There was some indication that for both valve types the noisiest valves were associated with a reduced value of g_m and emission, but there was no significant difference between the values of g_m and I_a of the best and the moderate ves. It was concluded that although measurements of g_m d I_a might be used to reject the worst specimens, they uld not help to select the best.

The "aging" of valves by running them for many hours der the correct operating conditions is sometimes recomended. Enquiries from the manufacturers elicited the ormation that all the types tested were aged "adequately" fore issue. This was borne out for the EF37A and 6BR7 lves by the fact that further aging for one hundred hours d no effect.

ble 2. *Comparison between valve types. Wide band noise.* uivalent bandwidth *400 c/s (half-power points* 10 *and* 300 *c/s)*

		Noise (μV peak-to-peak)		
Valve type	*Number tested*	*Range (pairs of valves)*	*Best pair*	*Best individual alone*
ullard EF37A	20	2·2 to 20	2·2*	1·6
ullard EF40	50	6·3 to 40	6·3	4·5
sram Z729	50	6·5 to 7·7	6·5	4·6
imar 6BR7	50	5·8 to 18	5·8	4·1

* Selection from two further batches of twenty-five valves each er brought to light a considerably better pair (Section 6).

ble 3. *Approximate operating conditions of valve types for tests summarized in Table 2*

	Vf (V)	*Va(V)*	*Ia (mA)*	*Vg (V)*	*μ*	*r_a (kΩ)*	*g_m (mA/V)*
F37A	4	45	0·7	−0·7	25	17	1·5
F40	4	47	0·7	−0·4	20	18	1·1
729	4	47	0·5	−0·2	20	20	1·0
3R7	4	48	0·7	−1·2	20	18	1·1

In view of these results the type EF37A was chosen for l further work, and an investigation of the relationship etween the noise and the operating conditions for this type as undertaken.

5. THE RELATIONSHIP BETWEEN THE VALVE NOISE AND THE OPERATING CONDITIONS

The two best individuals of the batch of twenty EF37A alves were tested separately in the circuit of Fig. 2. The equency response of the system was limited at the higher equencies as was explained in Section 4. The grid bias as adjusted by altering R_K. A high value of anode load as chosen so that the anode current did not vary widely ith the grid bias for the triode configuration.

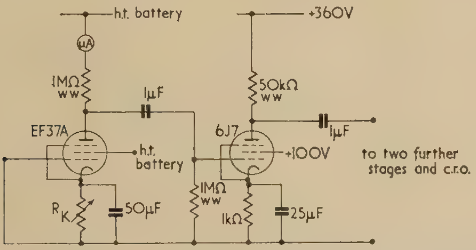

Fig. 2. Circuit for investigating the relationship between valve noise and operating conditions

Fig. 3 shows the relationship between the noise and the id bias for a pentode-connected valve, the anode current ing varied by altering the screen potential. Similar curves ere obtained for the triode-connected condition: in this se the anode current was altered by changing the h.t. pply. For a given value of grid bias and anode current, there was little to choose between the triode and pentode connexion; this indicated that partition noise (Section 3.5) was unimportant.

The curves showed a marked dependence of noise on grid bias, the optimum bias being about −0·5 V. This is in agreement with the curves given by Nicoll and Warner(23) for a CV138 valve. Furthermore, the curves showed a marked reduction of noise with increasing anode current; Nicoll and Warner reported a similar result, but in their case a flat minimum was obtained at an anode current of about 0·2 mA. Dalbert(24) also reported a minimum, lying at about 2 mA for a type R122N valve. However, in his experiments the anode current was altered by adjusting the grid bias, and the separate effects of these two parameters were not distinguished.

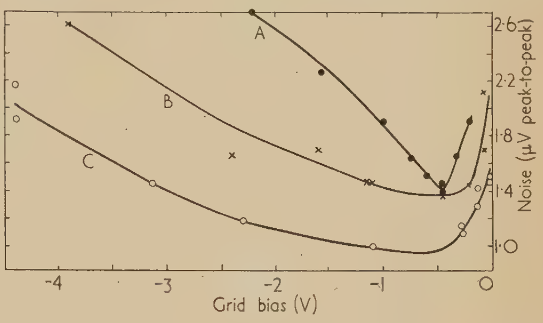

Fig. 3. Relation between noise and grid bias, at three different anode currents. Pentode-connected EF37A valve (selected)

Curve *A*, $I_a = 50\ \mu$A; curve *B*, $I_a = 200\ \mu$A; curve *C*, $I_a = 400\ \mu$A.

Changing the heater voltage from 6 to 4 V did not affect the noise, provided that the grid bias and anode current remained constant. Conflicting reports on this point appear in the literature: they may perhaps be explained by a failure to maintain these other conditions constant.

Finally, the two valves were set up in a balanced pentode stage with anode loads of 1 MΩ and a common cathode load of 150 kΩ, and the noise was measured at various grid voltages for a constant anode current. It was found that the magnitude of the noise at each grid bias was equal to the square root of the sum of the squares of the values previously measured for each valve separately. This confirmed the assumption (Section 2) that a double stage of this type, with a common cathode load, can be analysed from the noise generating point of view as two simple stages the contributions of which are uncorrelated.

In view of these results it was realized that the original circuit of Fig. 1 was operating under reasonably favourable conditions, and it was retained for further measurements on the noise spectrum.

6. SPECTRA OF AMPLIFIER NOISE

The spectrum of the amplifier noise was investigated for the double triode circuit of Fig. 1 using the wave analyser. The results are shown in Fig. 4 for three pairs of EF37A valves along with points plotted from the results of other workers who have published absolute values in this frequency range. Curve (5) is for the best pair selected from the first batch of twenty. Curves (6) and (7) are for two other pairs of EF37A valves, selected from two further batches of twenty-five each. The curves flatten out at high frequencies to a value which can be attributed to anode shot noise. For the EF37A valves this was 6·5 [curves (5) and (6)] and 6·8 [curve (7)] mμV per $\sqrt{1}$ c/s, compared with the value 6·5 calculated from the formula of Gillespie (Section 3.2). It is fortuitous that the agreement is so close considering the experimental error and the uncertainty in the value of the space charge smoothing factor.

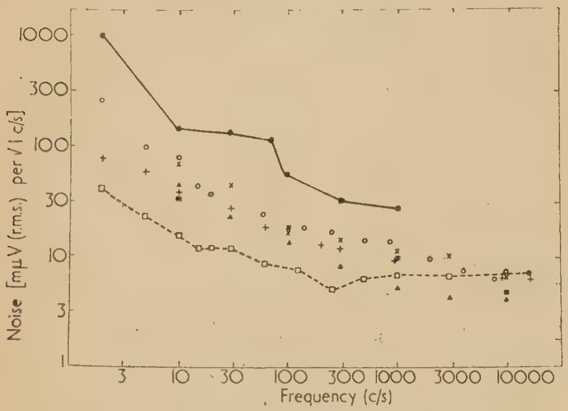

Fig. 4. Spectra of amplifier noise

Curve (1) ●——● = Van Wijngaarden and others (1952). AF7.(25)
Curve (2) × = Harris and others (1946). VR65.(26)
Curve (3) ▲ = Harris (1948). SP41.(22)
Curve (4) ■ = Bogle (1948). 6AC7.(27)
Curve (5) ○ = present work. A pair of EF37A valves.
Curve (6) + = present work. Second pair of EF37A valves.
Curve (7) □ - - - □ = present work. Third pair of EF37A valves.

Spectra were also plotted for a pair of 6BR7 valves and for two pairs of "noisy" EF37A valves. These all showed the same trend with frequency, and were still falling towards shot noise level at 10 kc/s. The spectra of the noisier valves fell with a smaller slope than the value of −0·5 predicted by the $1/f$ law. The spectra of the three best pairs of EF37A valves were replotted after deduction of the shot noise and were found to correspond approximately to the following equations:

$$\overline{\Delta V^2} = \left[\frac{(4{\cdot}4 \times 10^{-14})}{f^{0{\cdot}94}}\right]\delta f$$

$$\overline{\Delta V^2} = \left[\frac{(0{\cdot}92 \times 10^{-14})}{f^{0{\cdot}78}}\right]\delta f$$

and

$$\overline{\Delta V^2} = \left[\frac{(0{\cdot}41 \times 10^{-14})}{f^{1{\cdot}3}}\right]\delta f,$$

compared with Gillespie's formula

$$\overline{\Delta V^2} = \frac{(10 \times 10^{-14})}{f}\delta f \quad \text{(Section 3.4)}$$

It is clear that the formula can only be used as a very rough guide, as Gillespie himself pointed out.(15)

The discovery of a pair of valves which had a better noise performance at low frequencies than any others reported in the literature can only be regarded as very fortunate. The selection was from a total of only seventy valves in three separate batches ordered at intervals of about two years. Further selection from, say, 1000 tubes might bring to light even better individuals.

For the band of frequencies used for the electromyogra amplifier (10 to 2300 c/s) the wide band noise generated the two pairs of valves corresponding to the curves (5) and of Fig. 4 was about 4 μV peak-to-peak (0·8 μV r.m. corresponding to an equivalent noise resistance of 16 k The noise generated by the best pair was 1·9 μV peak-to-pe (0·38 μV r.m.s.), corresponding to an equivalent no resistance of 2·9 kΩ. This was only slightly greater than value for shot noise alone (2·8 kΩ), as was to be expect from the spectrum [curve (7) of Fig. 4], which showed th the flicker noise merged into shot noise at the exceptiona low frequency of 100 c/s. It is clear that this pair of val fulfilled the first requirement mentioned in the Introductio for an amplifier with a high input impedance and equivale noise resistance less than 5 kΩ.

7. IMPROVEMENT OF THE SENSITIVITY BY MEANS OF AN INPUT TRANSFORMER

The second requirement discussed in the Introduction w for an amplifier of lower input impedance and a noise res tance less than 500 Ω, and to achieve this a step-up tran former was designed and constructed by Messrs. Andec L Particular attention was paid to the Mumetal screen, avoid pick-up from magnetic fields. The primary inducta was 300 H, the primary resistance 250 Ω, the seconda resistance was 14 kΩ and the step-up ratio 1 : 10. T was tested with the amplifier of Fig. 1; the secondary w centre-tapped to provide the earth connexion. Measur ments on the frequency response of the system with vario source resistances showed that, for source resistances up 1 kΩ, the response was hardly modified by the transform at low frequencies, and somewhat improved at the hi frequency end of the range by the expected resonance, about 2·5 kc/s, of the secondary capacity and the leaka inductance. Above 3 kc/s the response fell off steeply. T equivalent bandwidth was 2·3 kc/s and the equivalent noi resistance of the system with the input terminals connect together, averaged over the band, was about 350 Ω. T noise spectrum is shown in Fig. 5 together with the noi spectrum of the amplifier by itself. The improvement d to the transformer at low frequencies, where the flicke noise of the amplifier predominated, was about ten time i.e. the step-up ratio of the transformer, as expected. A high frequencies the noise referred to the input terminals o the transformer increased as the effective gain of the trans former decreased. In the middle range, from 30 to 2000 c/ the noise was constant with frequency and equal to the therma noise generated by a resistance of about 300 Ω. The nois resistance in this range was expected to be about 390 Ω made up of 250 Ω (the primary resistance) plus 140 Ω (th

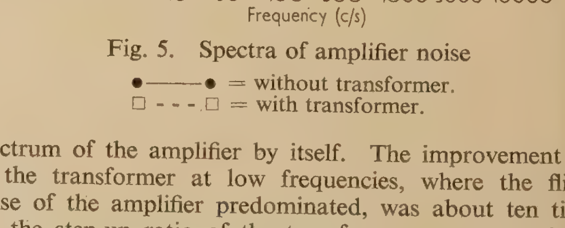

Fig. 5. Spectra of amplifier noise

●——● = without transformer.
□ - - - □ = with transformer.

stance of the secondary referred to the primary). This crepancy was within the experimental error of the noise asurements (corresponding to a difference between 2·2 2·5 mμV per $\sqrt{1}$ c/s).

his result is of considerable interest, since it shows that h a transformer can be used to increase the sensitivity of ow-frequency amplifier without itself introducing any litional source of noise other than the expected thermal stance noise. It had been anticipated that the Barkusen effect in the core resulting from small changes in gnetization induced by stray fields, or the thermal agitation the elementary magnetic zones, might introduce additional se. Another advantage of the input transformer is that provides a high degree of rejection of in-phase interference d can be followed by single-valve amplifying stages.

The transformer-amplifier system has been successfully ployed to obtain measurements of the "background ise" generated by the tissues. This was shown to be eater than the thermal noise expected on the basis of pedance measurements.(28)

ACKNOWLEDGEMENTS

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REFERENCES

1) Joseph, J., Nightingale, A., and Williams, P. L. *J. Physiol.*, **127**, pp. 617–625 (1955).
2) Nightingale, A., and Allsopp, C. B. "Medical Aspects of Non-destructive Testing." A chapter in *Progress in Non-destructive Testing*. Edited by E. G. Stanford (London: Heywood and Co. Ltd.).
3) Parnum, D. H. *Wireless Wld*, **51**, pp. 337–340 and 373–376 (1945).
(4) Offner, F. F. *Proc. Instn Elect. Engrs*, **35**, pp. 306–310 (1947).
(5) Gray, J. W. *Vacuum Tube Amplifiers*. Edited by C. E. Valley and H. Wallman, p. 447 (New York: McGraw-Hill Book Co. Inc., 1948).
(6) Toennies, J. F. *Rev. Sci. Instrum.*, **9**, pp. 95–97 (1938).
(7) Johnson, J. B. *Phys. Rev.*, **32**, pp. 97–109 (1928).
(8) Nyquist, H. *Phys. Rev.*, **32**, pp. 110–113 (1928).
(9) Moullin, E. B. *Spontaneous fluctuations of voltage* (Oxford: Clarendon Press, 1938).
(10) *Valve and Circuit Noise*. Department of Scientific and Industrial Research, Radio Research Special Report No. 20 (London: H.M. Stationery Office, 1951).
(11) Schottky, W. *Ann. Phys. (Leipzig)*, **57**, pp. 541–567 (1918).
(12) Schottky, W., and Spenke, E. *Wiss. Veröff. Siemens*, **16**, pp. 1–57 (1937).
(13) Schottky, W. *Physica*, **4**, pp. 175–180 (1937).
(14) North, D. O. *R.C.A. Rev.*, **4**, pp. 441–472 (1940).
(15) Gillespie, A. B. *Signal, Noise and Resolution in Nuclear Counter Amplifiers* (London: Pergamon Press, 1953).
(16) Pearson, G. L. *Physics*, **5**, pp. 233–243 (1934).
(17) Johnson, J. B. *Phys. Rev.*, **26**, pp. 71–85 (1925).
(18) Schottky, W. *Phys. Rev.*, **28**, pp. 74–103 (1926).
(19) Tomlinson, T. B. *J. Appl. Phys.*, **23**, pp. 894–899 (1952).
(20) Goldman, S. *Frequency Analysis, Modulation and Noise*, p. 226 (New York: McGraw-Hill Book Co. Inc., 1948).
(21) Tomlinson, T. B. *J. Brit. Instn Radio Engrs*, **14**, pp. 515–526 (1954).
(22) Harris, E. J. *Electronic Engng*, **20**, pp. 145–148 (1948).
(23) Nicoll, G. R., and Warner, F. L. Unpublished paper. Ministry of Supply (1951).
(24) Dalbert, J. *Vide*, No. 52–53, pp. 200–202 (1954).
(25) Van Wijngaarden, J. G., van Vliet, K. M., and van Leeuwen, C. J. *Physica*, **18**, pp. 689–713 (1952).
(26) Harris, E. J., Abson, W., and Roberts, W. L. Unpublished paper. Ministry of Supply (1946).
(27) Bogle, R. W. *Low Frequency Fluctuation Voltages in Vacuum Tubes*. Technical Monograph No. 137 (Baltimore: Applied Physics Laboratory, Johns Hopkins University, 1948).
(28) Nightingale, A. *Nature* [*London*], **181**, p. 192 (1958).
(29) Nightingale, A. *Ph.D. Thesis* (University of London, 1957).

An alternating-beam spectrophotometer

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[*Paper first received* 14 *February, and in final form* 17 *April*, 1958]

An alternating-beam system has been added to a Unicam type SP. 500 spectrophotometer for work over the wavelength range 2000–10 000 Å. In the visible spectrum a change of optical density of 0·0007 may be detected with an illumination intensity of 10^8 quanta per second and a response time of twenty seconds. The additional system is of simple construction and provides a means of measuring optical absorptions when the presence of other radiation prohibits the use of a single-beam instrument.

Spectrophotometers using double-beam methods of measurement possess several advantages: they eliminate the zero drift of d.c. instruments and the need to withdraw the specimen from the spectrophotometer beam for comparison measurements; they allow continuous records of optical absorption to be made; and they are capable of great accuracy. In addition, if the optical absorption of a luminescent specimen is to be measured or if, as in optical bleaching experiments, other radiation to which the photocell is sensitive must be present, a selective detecting system is essential. Though this may be achieved by light filters, if suitable ones are available, there is then a reduction of the spectral range in which absorption may be measured. Double-beam methods provide selective detection without such a reduction and have been found desirable in optical work on colour centres in the alkali halides. The paper describes a simple adaptation of the well-known Unicam instrument for these experiments.

The optical null method has been chosen as the one providing accuracy with the desired simplicity. The light beam from the monochromator is alternated between two paths, one of which passes through the specimen and the other through a calibrated attenuator. This is adjusted to produce an absorption equal to that of the specimen, and the equality is determined by the absence of an a.c. signal at the photocell on which both paths converge. The null detection is performed by a lock-in amplifier synchronized with the alternation of the light beam. This method avoids the need for constant alinement of the source and optical components, as is necessary when static division of the wave-front is employed,(1) and also the need for a highly linear detector which is required in methods where the optical transmission is proportional to the amplitude of an electric signal.(2,3)

OPTICAL SYSTEM

The monochromator of the Unicam instrument has a Littrow mounted quartz prism and delivers a divergent beam into the alternating unit. The width of the single entrance and exit slit is adjustable and controls the light intensity. The sources are a tungsten lamp and a hydrogen lamp. At a slit width of 0·01 mm, as is used for measurements in the visible spectrum, diffraction of the exit beam would cause it to pass through a larger area of the attenuator than does the geometrical beam, and over this larger area the attenuation would not be the same. The diffracted light is removed from both beams by placing a rectangular aperture between the exit slit and the alternating mirror, as shown in Fig. 1.

In the alternating unit the specimen beam is brought to a focus twice, first at the specimen and again at the photocell, while the comparison beam is brought to a focus only at the photocell. The wavelength range necessitates the use of front aluminized mirrors and loss of light is minimized by having as few reflecting surfaces as possible. To avoid confusion of the two light paths, reflexion from these mirrors must take place well off axis and astigmatism is thereby introduced. However, since the specimen beam changes shape between the two astigmatic images, it is possible to examine areas of the specimen of different proportions, as may be desirable from 1 cm × 1 mm to 4 × 4 mm, and also square areas of larger size. The final plane mirror in each beam brings both on to an identical area of the photocathode at approximately the same angle of incidence, thus avoiding possible errors due to variation in sensitivity over the surface of the photocathode.

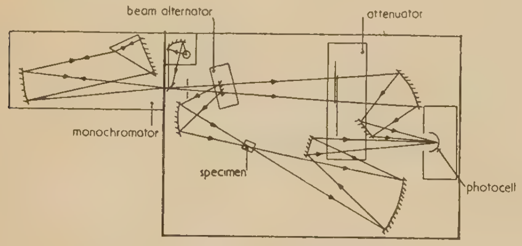

Fig. 1. The optical system

Measurement of optical density by a beam of convergent light introduces an error, since marginal rays of the beam traverse the specimen obliquely and are more absorbed than those transmitted perpendicularly. The error is present in most instruments where small specimens are examined, and since it is a constant fraction of the measured density it is usually ignored. In the present case the measured opti density is too great by less than $\frac{1}{2}\%$.

THE ATTENUATOR

Graded absorbing filters do not have a constant calibrati over the wavelength range, and a mechanical attenuator therefore used. Since the intensity distribution in the lig beam is governed by the shape of the source and the accura with which it is focused on the entrance slit of the mon chromator, uniformity of attenuation over the cross-secti of the beam is important, and the use of an iris diaphrag or similar device is prohibited.

The attenuator (Fig. 2) consists of two interdigitati combs having triangular teeth, which intercept the light bea from either side. Being situated where the comparison bea has a large cross-sectional area it is sufficiently large to constructed to normal tolerances. One comb is fixed a the other moves horizontally on three ball races running V-grooves. Thus the light beam passes a number of parallel-sided slits of variable width, which provide quasi-uniform attenuation over the beam. The taper and length of the teeth are such that when the points of the movable comb lie just to the left of the beam, as shown in Fig. 2, the attenuation is less than that caused in the specimen beam by reflexion losses at the two additional mirrors in this beam. Thus even when the specimen is 100% transparent, equal intensity is obtained in the two beams without withdrawing the movable comb to the right of the position shown in the figure. Thus uniform attenuation is always preserved and measurements are independent of all but gross errors of collimation.

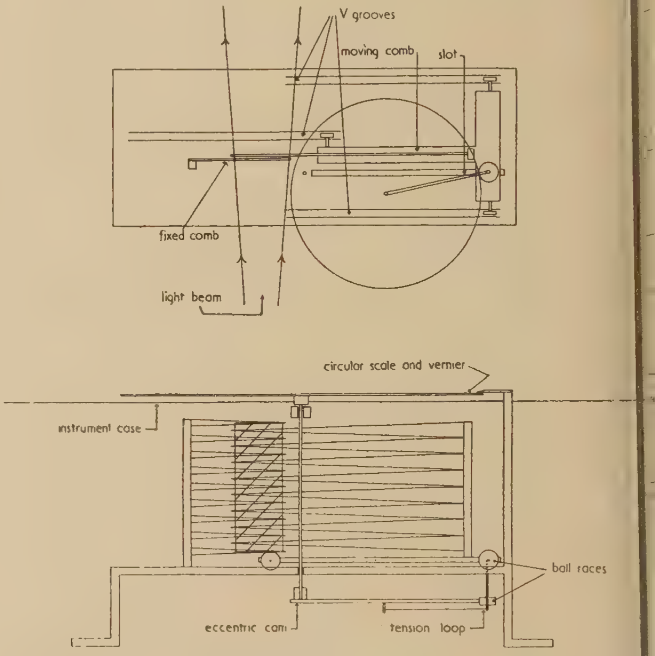

Fig. 2. The attenuator, plan and elevation

Since, in the author's experiments, observations are recorded in terms of optical density (log I_O/I_T), the movable comb is driven by an eccentric circular cam, which by expanding the movement at low transmission, where a given change in transmission represents a larger change in optical

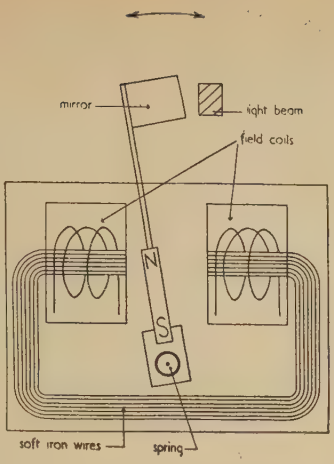
mirror
light beam
field coils
N
S
soft iron wires
spring

Fig. 3. The beam alternator

density than it would at high transmission, provides a more linear relationship between optical density and position as recorded on a circular scale. This drive is satisfactorily free from backlash. The position of the circular scale is controlled manually.

The attenuator is calibrated in position from the potentiometer system of the Unicam. The intensity of light from the monochromator is maintained constant during calibration over one unit of optical density and is then increased so that the potentiometer may be again used to calibrate the next unit. It is thus necessary to rely on the linearity of response of the photocell only over one unit of optical density during calibration over an optical density range from nought to four.

ALTERNATION OF THE LIGHT BEAM

The mirror by which the light beam is alternated between the two paths must meet two requirements; its plane of reflexion must remain fixed (or the light beam will examine

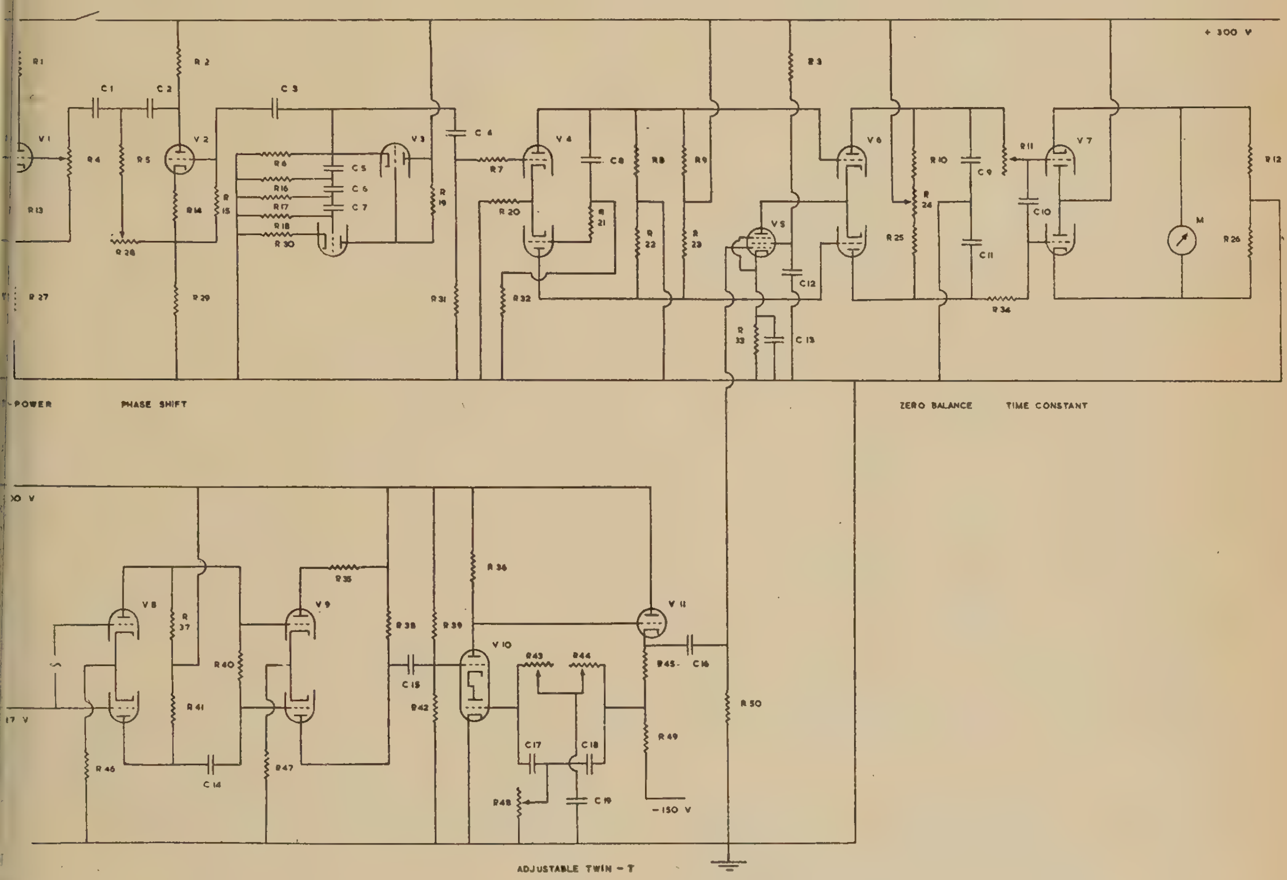
+ 300 V
R1
R2
C1
C2
C3
C4
V1
V2
V3
V4
V5
V6
V7
R4
R5
R6
R16
R17
R18
R30
C5
C6
C7
R13
R14
R15
R28
R27
R29
R31
R19
R7
R20
R21
R32
C8
R8
R9
R22
R23
R3
R33
C13
C12
R10
C9
R24
R25
C11
R11
C10
R34
M
R12
R26
POWER
PHASE SHIFT
ZERO BALANCE
TIME CONSTANT
00 V
17 V
V8
V9
V10
V11
R37
R40
R41
R46
C14
R47
R35
R38
R39
R42
C15
R36
R43
R44
R45
C16
C17
C18
R48
C19
R49
R50
- 150 V
ADJUSTABLE TWIN - T

Fig. 4. Electronic system of the alternating-beam spectrophotometer

R_1 = 1 kΩ, 5 W, field coil
R_2 = 2 kΩ, 5 W
R_3 = 220 kΩ, 1 W
R_4 = 250 kΩ pot
R_5 = 5 kΩ, $\frac{1}{4}$ W
R_6 = 270 kΩ, $\frac{1}{4}$ W
R_7 = 10 MΩ, $\frac{1}{4}$ W
R_8 = 100 kΩ, $\frac{1}{2}$ W
R_9 = 200 kΩ, 1 W
R_{10} = 68 kΩ, 10 W, w.w.
R_{11} = 3 MΩ pot
R_{12} = 220 kΩ, 1 W
R_{13} = 56 Ω, $\frac{1}{4}$ W
R_{14} = 470 Ω, $\frac{1}{2}$ W
R_{15} = 200 kΩ, $\frac{1}{4}$ W
R_{16}, R_{17} = 470 kΩ, $\frac{1}{4}$ W
R_{18} = 400 kΩ, $\frac{1}{4}$ W

R_{19} = 560 kΩ, $\frac{1}{4}$ W
R_{20} = 1 kΩ, $\frac{1}{4}$ W
R_{21} = 10 MΩ, $\frac{1}{4}$ W
R_{22} = 100 kΩ, $\frac{1}{2}$ W
R_{23} = 200 kΩ, 1 W
R_{24} = 5 kΩ pot., w.w.
R_{25} = 68 kΩ, 10 W, w.w.
R_{26} = 220 kΩ, 1 W
R_{27} = 1 kΩ, 5 W, field coil
R_{28} = 500 kΩ pot
R_{29} = 2 kΩ, 5 W
R_{30} = 4·7 kΩ, $\frac{1}{4}$ W
R_{31}, R_{32} = 1 MΩ, $\frac{1}{4}$ W
R_{33} = 680 Ω, $\frac{1}{4}$ W
R_{34} = 56 kΩ, $\frac{1}{4}$ W
R_{35} = 150 kΩ, $\frac{1}{4}$ W
R_{36} = 220 kΩ, $\frac{1}{4}$ W

R_{37} = 330 kΩ, $\frac{1}{4}$ W
R_{38} = 150 kΩ, $\frac{1}{4}$ W
R_{39} = 2 MΩ, $\frac{1}{4}$ W
R_{40} = 1 MΩ, $\frac{1}{4}$ W
R_{41} = 330 kΩ, $\frac{1}{4}$ W
R_{42} = 1 MΩ, $\frac{1}{4}$ W
R_{43}, R_{44} = 250 kΩ pot.
R_{45} = 200 kΩ, $\frac{1}{4}$ W
R_{46} = 27 kΩ, $\frac{1}{4}$ W
R_{47} = 120 kΩ, $\frac{1}{4}$ W
R_{48} = 150 kΩ pot.
R_{49} = 150 kΩ, $\frac{1}{4}$ W
R_{50} = 470 kΩ, $\frac{1}{4}$ W

C_1, C_2 = 0·25 μF, 350 V working
C_3, C_4 = 0·1 μF, 350 V working
C_5, C_6, C_7 = 0·01 μF, 350 V working

C_8 = 0·1 μF, 350 V working
C_9 = 16 μF, electrolytic, 450 V
C_{10} = 8 μF, 350 V working
C_{11}, C_{12} = 16 μF, electrolytic, 450 V
C_{13} = 250 μF, electrolytic, 25 V
C_{14} = 0·25 μF, 350 V working
C_{15}, C_{16} = 0·1 μF, 350 V working
C_{17}, C_{18} = 0·1 μF } matched
C_{19} = 2 × 0·1 μF } mica

V_1, V_2 = 6 CH6
V_3, V_4 = 6 SL7
V_5 = 6 AK5
V_6, V_7 = 6 SN7
V_8, V_9, V_{10} = 6 SL7
V_{11} = $\frac{1}{2}$ 6 SN7

M = 1—0—1 milliammeter, 500 Ω

different parts of the specimen during the cycle) and the phase of the motion must be controlled. A rotating mirror was originally used, but a small oscillating mirror which interrupts the beam from one side has been found more satisfactory. It is shown in Fig. 3.

A permanent magnet is supported on the same axle as the mirror, and oscillation of unambiguous phase maintained by the field coils, which form the 1 kΩ anode and cathode loads of the first type 6CH6 valve (V_1, Fig. 4). A torsion spring running longitudinally through the hollow axle balances the steady magnetic field, and is such that the natural frequency of oscillation of the mirror assembly is well removed from the driven frequency. Thus any change in the frictional couple on the axle does not affect the phase of alternation.

ELECTRONIC SYSTEM

The electronic system is shown in Fig. 4. A frequency of beam alternation of 15 c/s has been chosen as being sufficiently high for flicker noise to be insignificant, yet low enough for the power for beam alternation to be easily obtained. Because of its good frequency stability, a phase-shift oscillator is used to generate oscillations. It drives the type 6CH6 power tube V_1 by way of a second type 6CH6 tube V_2, used as a phase control.

The oscillator triggers a cathode-coupled multivibrator of similar frequency, giving a square wave which is used to switch the lock-in amplifier. This amplifier is followed by a smoothing circuit, the time constant of which is adjustable between a half and twenty seconds. The final triode and milliameter form a d.c. voltmeter.

The Unicam photocell-electrometer circuit provides a signal across its output meter and this signal appears in Fig. 4 at the point labelled +27 V. It receives an amplification of 2500 and is filtered by the twin-T cascode circuit. It is then rectified by the lock-in amplifier.

The output meter of the Unicam instrument and its photocell-electrometer unit are both very microphonic, and good performance has only been obtained after mounting these on anti-vibration supports. All earth connexions are made to a common point on the Unicam chassis and the two amplifying stages are screened and placed within the Unicam case. However, the effect of external electric disturbance is not completely removed and obviously originates in pick-up across the electrometer grid. In the absence of external disturbance, the observed noise is approximately twice the calculated thermal noise in the grid resistor of the electrometer.

PERFORMANCE

The minimum detectable change in optical density depends on the light intensity employed and the response time of the smoothing circuit. In the visible spectrum, with a typical intensity of 10^8 quanta per second and a response time of twenty seconds, the minimum detectable change is 0·0007.

Since the specimen does not have to be mounted close to the monochromator exit slit a large space is available for auxiliary apparatus, for example a cryostat or furnace, and the specimen does not have to be removed from the spectrophotometer for treatment. Small specimens may be use down to 4 mm square, and measurements are accurate reproducible since the attenuator is the only moving p which controls the ratio of light intensity in the two beam This reproducibility, together with the fact that the specim is not disturbed, gives reliability where changes occurri after various treatments have to be measured.

A typical use of the instrument is the determination of t initial slope of an optical bleaching curve of colour centr created by X-irradiation. This slope is relevant in that gives a measure of the bleaching efficiency in the only co ditions which are mathematically tractable, namely, wh the optical density is uniform throughout the specime Fig. 5(*a*) shows the bleaching curve and Fig. 5(*b*) an enlarg

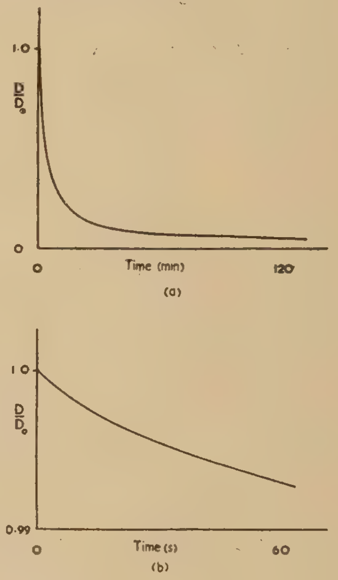

Fig. 5. A typical optical bleaching curve of colour centres in an alkali halide crystal. Fractional optical density is plotted against time

ment of the initial portion. It can be seen that the initi slope must be measured over a small range since the bleachi curve has such a rapid change of gradient. The curvature apparent over an optical density range of 0·002, and thus th initial slope must be determined within this range, giving th determination an accuracy of ±4% when the full sensitivi of the instrument is used. Since the author also has a X-ray tube mounted within the spectrophotometer, a succes sion of colouring and bleaching experiments may be per formed without any manipulation of the specimen and th results may be reliably compared.

REFERENCES

(1) Etzel, H. W. *J. Opt. Soc. Amer.*, **43**, p. 87 (1953).
(2) King, W. H. *J. Opt. Soc. Amer.*, **43**, p. 866 (1953).
(3) Hariharan, P., and Bhalla, M. S. *J. Opt. Soc. Amer* **47**, p. 378 (1957).

An electrodynamic magnetic field gradiometer employing a microvibration technique

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A simple arrangement is described for measuring magnetic field inhomogeneity in any direction to an accuracy of at least 10^{-3} G/cm. The essential part is a very small coil fed by a low frequency a.c. so as to possess an alternating moment and is held, in the (non-homogeneous) magnetic field under test, at the end of a clamped-free elastic reed. When the coil axis is set parallel to the lines of force, it will experience an alternating electrodynamic force (proportional to the field gradient) having a component parallel to the field direction and two other components across the field direction. The coil can follow one or the other of these forces according to the way in which it is constrained to move. The problem thus resolves itself into microvibration measurement. A capacity pick-up circuit is used for this purpose.

INTRODUCTION

or many purposes it is desirable to perform a rapid test for agnetic field homogeneity or to conduct a measurement of e magnetic field gradient. The device used in this connexion known as the gradiometer, and is particularly useful in the ploration of magnets designed for special purposes such as rticle accelerators.

Magnetic field gradients may be accurately studied from e shape of the nuclear induction signal as suggested by ick.(1) Simpler, though less accurate, methods depend on ectromagnetic induction. Frazer and others(2) described a radiometer based on the measurement of the e.m.f. induced a small search coil vibrated at 100 c/s by mechanical oupling to the diaphragm of a loudspeaker. Karmohapatro nd Majunder(3) also measured the gradient by the induction a coil maintained in vibration at 100 c/s by means of an .c. excited relay. Brown and Bitter(4) measured field homogeneity by induction in a coil rotating across the eld in a circular path.

The gradiometer described in the present paper is based n the alternating electrodynamic forces experienced by a mall probe coil fed by a low-frequency a.c. These forces re measured as microvibrations executed in the direction of he gradient.

BRIEF DESCRIPTION

Fig. 1(*a*) illustrates the basic features of the electrodynamic gradiometer. The probe coil *L* is air-cored, and is 0·35 cm n length, 0·30 cm in inner diameter and 0·50 cm in outer diameter. It is wound with several hundred turns of enamelled copper wire s.w.g. 48, and is carried by a brass reed *R* (5 × 0·3 × 0·02 cm) whose breadth is alined either perpendicular to the coil axis [Fig. 1(*b*)], or parallel to it [Fig. 1(*c*)]. In the first case, the arrangement is meant for measuring gradients (dH_y/dy) along the field direction. The coil axis is set along the field and the effective electrodynamic force acts in the *y*-direction, there being no freedom of motion along the other axes by virtue of the stiffness of the structure. In the second case, the coil axis is again in the field direction but the effective force now acts in a perpendicular direction, say the *x*-direction, and gives rise to vibrations whose amplitude is a measure of dH_y/dx. The reed, which responds to the vibrations, is fixed to an earthed brass handle *H*, which also supports an insulated capacity electrode *D* whose distance from the vibrating reed *R* can be adjusted by a screw *W*. The handle forms one lead of the current passing in the coil; the second lead is connected to an insulated tag (not shown in the figure), fixed to the handle. The length of the reed can be adjusted so that its natural frequency of transverse vibrations is the same as that of the current in the coil, which may conveniently be the mains 50 c/s.

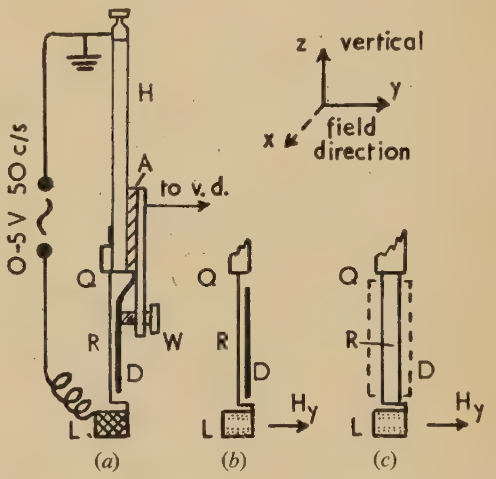


Fig. 1. The electrodynamic gradiometer

L = air-cored probe coil
Q = clamp
D = capacity electrode
v.d. = vibration detector
R = elastic brass reed
H = supporting brass handle
W = sensitivity adjusting screw
A = mica insulation

(*a*) General sketch. In (*b*) the breadth of the reed is perpendicular to the coil axis to give dH_y/dy in terms of vibrations in the *y*-direction. In (*c*) the breadth of the reed is parallel to the coil axis to give dH_y/dx in terms of vibrations in the *x*-direction which is supposed to be perpendicular to the plane of the figure.

THEORETICAL SENSITIVITY

In a region where the field gradient in the possible direction of motion is *G*, the magnetic force on the probe coil is $GM \cos qt$, where *M* is the amplitude of the magnetic moment of the coil and *q* is the angular frequency of the energizing a.c. The equation of motion of the loaded reed, regarded as a system with one degree of freedom, is of the form

$$d^2y/dt^2 + r\,dy/dt + w^2y = (GM/m)\cos qt \qquad (1)$$

where m is the effective mass, r the damping factor $= q\delta/\pi$, δ the logarithmic decrement and $w^2 = Ebd^3/4ml^3$ the square of the natural transverse pulsatance. The resonance amplitude is given by

$$y_0 = GM/mrq = \pi GM/q^2 m\delta \qquad (2)$$

This equation indicates that the response, measured as a displacement amplitude, varies as M, $1/m$, $1/q^2$ and $1/\delta$. Reasonable amount of damping is desirable rather than objectionable as it promotes stability against frequency fluctuations and ensures insensitivity against mechanical disturbances. The response is inversely proportional to the square of frequency. A satisfactory value for the latter is about 20 c/s, but it may be more convenient to operate the coil at the supply frequency of 50 c/s. The remaining factors at our disposal to secure optimum performance is the ratio M/m. The magnetic moment of the coil is determined by the ampere-area, and is limited primarily by the heat dissipation in the coil. We may thus write $M = k\sum_1^n \pi r^2$, where k is the maximum permissible current and n the number of turns. Using a thin reed, the effective mass will be mainly localized in the coil and we may put $m = \lambda\sum_1^n 2\pi r$, where λ is the mass per unit length of the wire. Thus

$$M/m = \text{const.} \sum_1^n r^2 / \sum_1^n r \qquad (3)$$

from which we see that larger values of r favour higher sensitivity. The maximum radius of the coil, however, is restricted by the inevitably small volume which the coil ought to occupy.

The vibration displacement may be conveniently measured in terms of the capacity change Δc, between the reed and a capacity electrode D situated in close proximity. We may regard the deflexion y_0 at the end of the reed as equivalent to an average displacement of the whole reed parallel to its plane by an amount $0{\cdot}4y_0$, which is the average deflexion throughout the entire length. Thus

$$\Delta c/c = 0{\cdot}4 y_0/t \qquad (4)$$

where c is the capacity between the reed and the pick-up electrode, and t their mean separation. Hence

$$\Delta c = 0{\cdot}4\pi cGM/tq^2 m\delta \qquad (5)$$

The pick-up circuit used by the authors(5) can detect a periodic capacity change of the order 10^{-4} pF, for which the output indication is 5 mV. Taking $\Delta c = 10^{-4}$ pF, $c = 10$ pF, $t = 0{\cdot}01$ cm, $m = 0{\cdot}5$ gm, $q = 120$ rad/s, $M = 0{\cdot}5$ c.g.s. units, $\delta = 0{\cdot}05$, the minimum gradient that can be detected under the stated conditions is 3×10^{-4} G/cm.

DISCUSSION OF THE POSSIBLE SOURCES OF ERROR

The signal given by (5) might be affected by noise due to two different origins. The first is the noise due to mechanical disturbances. This is generally smaller than the limit of the sensitivity of the apparatus, unless the disturbances are abnormally high. The proximity of the reed from the capacity plate assists in suppressing this noise by providing sufficient air damping, and in general no unusual precautions against mechanical shocks are necessary. The second origin of noise is the couple which might be associated with magnetic force when the field has a component perpendicu to the axis of the gradiometer coil. This couple gives rise forced torsional oscillations whose amplitude θ may easily shown to be approximately given by

$$\theta = MH'/Ip^2$$

where H' is the component of the field at right angles to t coil axis, I the moment of inertia of the probe coil about t reed axis and p the natural torsional pulsatance of the ree and is supposed to be sufficiently greater than the natu flexural pulsatance $q(p > 10q)$. The shear θ gives rise to periodic capacity change whose amplitude, to a first ord of approximation in θ, is

$$(\Delta C)' = C\alpha\theta b^2/12t^2$$

where α is the small inclination between the reed and t capacity plate in the direction of the breadth b of the r and is of the order of 0·01 rad.

Thus, making use of the well-known relation between and q in terms of the dimensions and the elastic moduli the reed, the signal-to-noise ratio

$$(\Delta C)/(\Delta C)' = 6{\cdot}4\pi Gntl^2/\alpha\delta H'Eb^2$$

where l is the length of the reed, n its rigidity modulus, an E its Young's modulus. Taking H' to be numerically of t same order of magnitude as the gradient G, the signal-to-nois ratio is of the order of 10^4, which is extremely high. Conse quently, even in the presence of a large field compone across the coil axis, the couple has a negligible effect on th indication.

Another point worthy of consideration is the effect of t current i' induced in the gradiometer coil due to its vibratio in the non-homogeneous field. The induced current expresse in e.m.u. is

$$i' = AGqy_0 \,.\, 10^{-9}/R \qquad (9$$

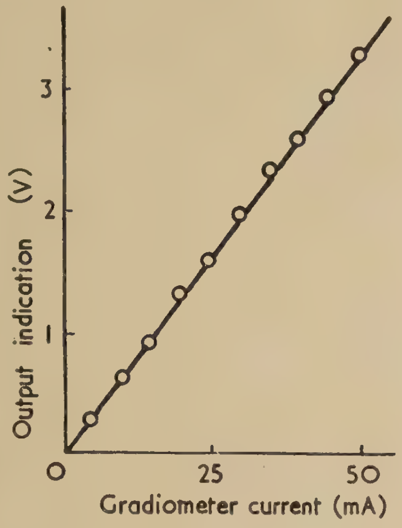
where R is the resistance in the circuit of the probe coil, and A is the total area of the coil. Using (2) and remembering that $M = iA$, where i is the applied current, we get

$$i'/i = \pi A^2 G^2 \,.\, 10^{-9}/Rqm\delta \qquad (10$$

Even for values of G as high as 1000 G/cm, the ratio i'/i for a circuit resistance of 1000 Ω is less than 1/100, which means that the magnetic moment of the coil due to the induced current is negligible in comparison with that due to the applied current, and, moreover, may be controlled through R.

Another question may arise about the disturbing effect on field distribution due to the moment of the gradiometer coil. Field distortion by the coil may best be investigated experimentally. We should expect the effect to be more pronounced when the coil is situated close to an unsaturated piece of iron which is magnetized by a weak field such as the earth's field. If such a distortion exists, it would increase as the moment of the coil is increased, and the relation between the moment of the coil and the output indication [see equation (5)] would not be linear in a linear measuring circuit. However, the linearity of Fig. 2 indicates that the distortion is undetectable, even for moments up to 0·5 c.g.s. units, corresponding to a gradiometer current of 50 mA. Accordingly, we conclude that under normal conditions of operation, where much smaller moments are used, the current in the gradiometer coil introduces no distortion.

nally, another point may also arise as to the effect of currents induced in the pole-faces by the alternating in the probe coil. The interaction of these currents on coil might interfere with the vibrations arising from the dient of the field. However, simple considerations show t this force is normally very small, and, moreover, has a quency which is double that to which the reed is resonant, d thus the reed will not respond to it.



ig. 2. Behaviour of gradiometer in presence of unsaturated iron

bsence of field distortion is shown by the linearity of output ndication against the moment of the gradiometer coil. The ata are taken under conditions of slight departure from sonance in order that the amplitude shall not increase ufficiently to affect the linearity of the measuring arrangement adversely.

CALIBRATION

The gradiometer may be calibrated under fixed operating nditions by observing the output indication in a known ld gradient, such as that due to a small magnet of known ment, or that due to a current in a circular coil at a point ng its axis, preferably distant $a/2$ from the centre, where is the radius of the calibrating coil. Fig. 3 shows a caliation curve produced under conditions of high sensitivity. considerable range of G may be covered by controlling e current in the probe coil. In measuring a field gradient the z-direction (see Fig. 1), the handle H has to be held rizontally, and in order to avoid the effect of gravity on e separation distance between the reed and the pick-up electrode, the gradiometer must be calibrated when similarly orientated.

The present device has been conveniently employed by the authors for magnetic field exploration, measuring magnetic moments of small magnets in terms of their field gradients, plotting magnetic lines of force, location of magnetic equatorial planes, location of the Curie region of maximum $H_y dH_y/dx$, and location of the region of maximum uniformity.

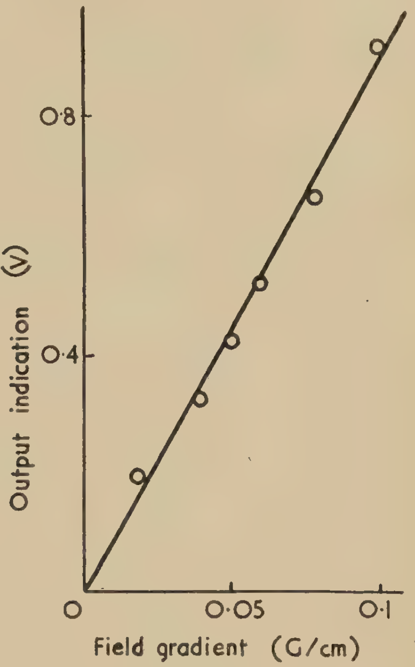


Fig. 3. Calibration curve of the gradiometer

Moment of the probe coil is about 0·5 pole cm or c.g.s. units, corresponding to a current of 50 mA. Resonant frequency 50 c/s. Sensitivity 8·5 mV per 10^{-3} G cm^{-1}. Noise level 5 mV.

REFERENCES

(1) Dick, L. *C.R. Acad. Sci.* [*Paris*], **239**, p. 1376 (1954).
(2) Frazer, J. *Rev. Sci. Instrum.*, **26**, p. 475 (1955).
(3) Karmohapatro, J. B., and Majunder, S. K. *Sci. and Culture*, **21**, p. 621 (1956).
(4) Brown, H. H., and Bitter, F. *Rev. Sci. Instrum.*, **27**, p. 1009 (1956).
(5) Yousef, Y. L., Girgis, R. K., and Mikhail, H. *Rev. Sci. Instrum.*, **23**, p. 959 (1955).

Laboratory and workshop notes

A method of programming the speed of linear traverse

By P. H. Hollins and D. W. Skidmore, Dunlop Research Centre, Fort Dunlop, Birmingham

[*Note first received* 24 *January, and in final form* 26 *February*, 1958]

A method is described for programming the speed of linear traverse in a predetermined and reproducible manner, the required movement being governed by the contour of an easily made and replaceable cam. The apparatus is being applied to the movement of a gas burner along a combustion tube in the microdetermination of carbon and hydrogen in organic compounds. Most automatic methods use a synchronous motor to move the burner at a constant speed over the entire distance travelled. Some control may be effected by intermittent operation of the motor using an "on–off" cycling switch, the effective speed being determined by the relative "on" and "off" times. If this speed is restricted to the slowest required at any point, satisfactory combustion can be achieved, but the method becomes time consuming. Ideally the speed should be variable along the tube using at all points the highest speed compatible with complete combustion. This may be done by varying the "on–off" ratio in relation to the burner position. This ratio can be controlled by a simple electro-mechanical device which operates as follows.

The synchronous motor M_1 drives the burner carriage by means of a lead-screw. It is connected to the a.c. mains through a micro-switch (1) which is rigidly mounted on a lever (2). The motor M_1 stops when the switch plunger is depressed by contact with cycling cam (3), which is rotated continuously at 4 rev/min by motor M_2. Cam (3) is shaped so that, whilst it is in contact with the plunger, the switch and lever are raised and lowered at a constant speed. When the downward travel of the lever is restricted by coming into contact with the programme cam (4), the plunger of the switch loses contact with the cycling cam and motor M_1 becomes energized. The time that contact is lost between the cycling cam and the switch plunger during any period of 15 s is dependent on the height of cam (4). This programme cam is positively geared to the burner lead-screw so that 360° rotation corresponds to the total burner travel. The height of this cam at any angular position establishes an "on–off" ratio for driving motor M_1 at the corresponding burner position. The best conditions for combustion are determined, for any particular type of sample, by manual operation of the burner and a programme cam is shaped to reproduce these conditions automatically. This cam is fitted to the apparatus by means of a knurled nut and will produce identical combustion conditions for all subsequ
samples.

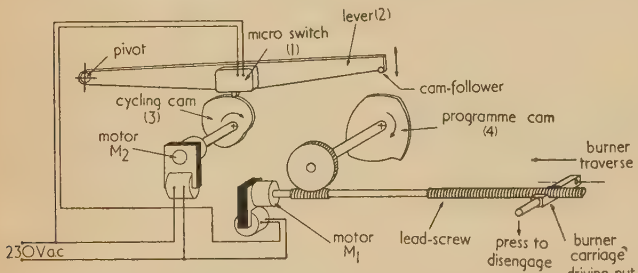


Diagram of programme controller

Programme cams may be cut from $\frac{1}{16}$ in. brass sheet, t
radial height at the point of contact with the lever bei
directly proportional to the effective burner speed. T
diameter of the cam follower is $\frac{1}{8}$ in. and, in cutting the ca
can be considered as making a point contact without intr
ducing a serious error into the speed programme. Mechani
considerations of cam and follower impose a limit
acceleration. In practice, speed can be increased by at lea
30% of maximum speed in $\frac{1}{4}$ in., and deceleration is u
limited. A lever is provided for disengaging the burn
carriage driving nut from the lead-screw for manu
operation.

It will be realized that in all positions of the programn
cam, the micro-switch must be depressed during ea
revolution of the cycling cam, otherwise the carriage drivi
nut will come permanently to rest.

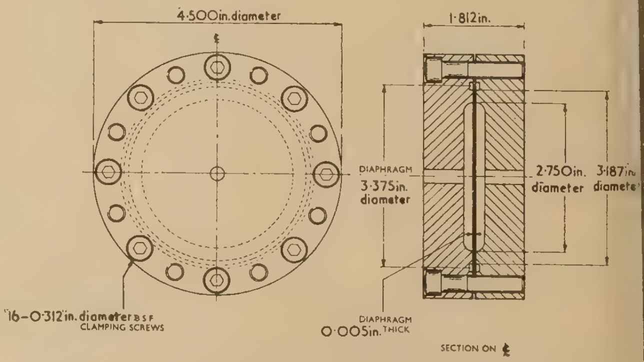
A note on the use of polytetrafluoroethylene in vacuum sea

By A. J. Davies, B.Sc., A.Inst.P., "Shell" Research Ltd., Thornton Research Centre, Chester

[*Note received* 5 *February*, 1958]

Polytetrafluoroethylene (P.T.F.E.) is often disappointing
gasket material because of its plastic deformation under loa
Reducing the thickness of the gasket to take advantage
the constraint at the clamping surfaces is helpful, but in o
experience gaskets even as thin as 0·005 in. are unreliable
vacuum seals when used at temperatures approaching 300° C
We have, however, had consistently good results with muc
thinner films, and the method of preparing them, develope
to seal a flexible diaphragm between flanges as shown in th
figure, may be of more general interest.

A piece of steel uniformly thick, flat and free from surfac
defects is selected for the diaphragm, cut about $\frac{1}{8}$ in. oversi
and ground at the edge to finished diameter; this remove
the metal stretched by cutting and obviates buckling. Th
disk is cleaned on both sides, first using fine abrasive pape
and then cathodically at a current density sufficient to caus
vigorous gassing in a saturated solution of caustic soda i
technical methanol. Copious washing with clean tap wate
leaves a strongly hydrophilic surface; the excess water
shaken off and the disk immersed whilst still wet in a pr



P.T.F.E. sealed joint for pressures between vacuum and 300 lb/in.^{2} and temperatures up to 300° C. The diaphragm is of spring steel, the flanges of stainless steel (18/8) and the clamping screws of steel tary aqueous dispersion of P.T.F.E. [Teflon Dispersion flon 30), from Laboratory Apparatus and Glass Blowing , Manchester]. Taking care to exclude dust and air bles, it is then transferred to a spider mounted on the tical shaft of a small electric motor, which supports it izontally at three points around the extreme edge. In it is spun about its centre (at about 500 rev/min) to ow off surplus dispersion and distribute the remainder as evenly thin film, which is dried with the aid of radiation m an incandescent lamp. The thoroughly dried film is tered by playing a soft bunsen flame on the still rotating k until the milky appearance of its surface suddenly nges to a transparent glaze, when heating is stopped tantly. Overheated P.T.F.E. gives off toxic gases. One us obtains a highly glazed tenacious P.T.F.E. coating, out 0·000 25 in. thick over the whole disk, with the ception of a swelling around the edge for which clearance provided in the flanges. With so little material to fill erstices it is essential that the clamping faces of the nges conform accurately; after turning they should be ess-relieved and then ground. The rather large examples ustrated were finally lapped together. Ample and well stributed clamping force must be provided.

When first assembled the seals are usually imperfect, but lding at a temperature of 275 to 300° C suppresses the ak after a few hours. Thereafter they may be cooled and heated repeatedly without deteriorating.

The author is indebted to the Directors, "Shell" Research td., for permission to publish this note.

A simple creep strain recorder for use with wire specimens

By J. Congleton, B.Sc., and R. N. Parkins, B.Sc., Ph.D., Department of Metallurgy, University of Durham, King's College, Newcastle upon Tyne

[*Note received* 10 *February*, 1958]

he difficulties of measuring creep strain in metals during he whole creep process are apparent in the shape of the ormal creep curve, which shows regions of widely differing train rate. The measuring instrument is required to be ufficiently sensitive to respond to the relatively small strains hich occur in the steady state region and yet, in some cases, o be capable of measuring the large total strain which the pecimen undergoes while, preferably, making a permanent ecord of the curve.

In his earliest work Andrade(1) used a cathetometer for measuring creep strain, and later, in conjunction with Chalmers,(2) devised a system of autographic recording, although from the point of view of the present work it was felt that a simpler method would be advantageous. The Martens extensometer(3) is probably used more than any other type in creep studies and it certainly has the advantages of simplicity and sensitivity, although, in its commonest form, could not readily be used for recording large creep strains. Electrical devices, such as strain gauges(4) and differential transformers,(5) and simple dial gauges readily lend themselves to recording techniques, but have limitations either in their sensitivity or in the range of extension with which they can cope. By a simple modification to the Martens principle a recording extensometer has been developed which is capable of high sensitivity and of measuring large total strains while remaining simple and inexpensive.

This has been achieved by replacing the rhomb with a rack and lever, the latter carrying a plane mirror, as shown in Fig. 1. *AB* and *CD* are the reference limbs which move parallel to one another as the specimen extends. *AB* carries a rack *R*, and *CD* a lever *L* pivoted at *P*. The lever has a plane mirror *M* attached with its axis of rotation coincident with the lever pivot. Three rollers are used to keep the reference limbs parallel, contact between the limbs and rollers being maintained by small springs. A guide rod *E* passing through a bush in the limb *CD* also assists in keeping the limbs parallel. The extensometer is attached to the lower loading shackle by light springs and rollers, so that its movement is in the same direction as the specimen extension. Any bending which this attachment would tend to impose upon the wire specimen is counteracted by another limb *FG* attached in the same way but on the opposite side of the loading shackle to that occupied by the extensometer. Because of the use of wire specimens it was found necessary to attach the reference limbs *AB* and *CD* to the grips which held the specimen, but by suitable specimen design (see later)

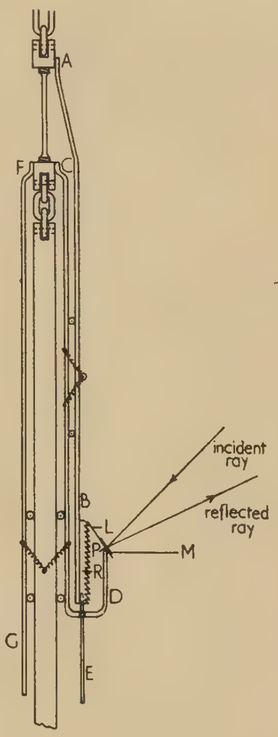


Fig. 1. Creep strain recorder

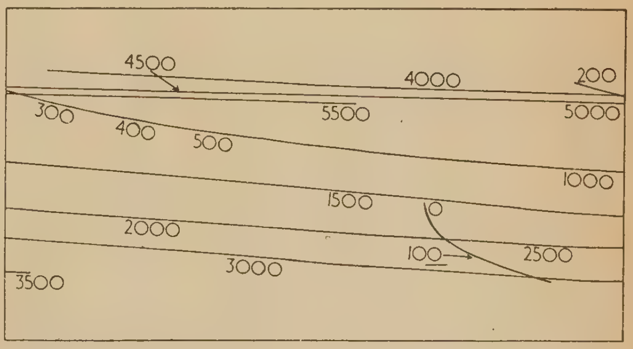


Fig. 2. Autographic creep strain record (numbers indicate time in minutes)

the measured extension could be restricted to a suitable gauge length on the specimen.

As the specimen extends the lever is raised by the knife edge of the rack until, with a further increment of extension, the lever falls to the next knife edge, whence the process is repeated as the extension continues. The mirror M is thus rotated through a small angle about the pivot P, then returned to its original inclination for an extension of the specimen equal to the distance between adjacent knife edges. The extension is determined by measuring the angular rotation of the mirror with an optical level, the movement of which is recorded on photographic paper affixed to a rotating drum. In the work for which the extensometer has been used a magnification of 40 has been found convenient; this was obtained with an optical lever of 60 in. and yielded a record of the type shown in Fig. 2.

SPECIMEN PREPARATION

The use of specimens of small cross-section (about ⅛ in. diameter or less) for tensile tests has the advantages of conserving material and of requiring low load apparatus. Difficulties arise, however, in that wires cannot be machined into specimens by normal techniques and the gripping of the unmachined specimen in pin-vices and the like is never very satisfactory, particularly if strain measurements are to be made between the two grips. This difficulty has been overcome by upsetting the ends of the specimen into steel collets, and although the technique has only so far been used with polycrystalline material there seems to be no reason why it should not be used with single crystals, providing the crystals are grown after the collets are attached to the wire.

The stock material used in conjunction with the extensometer was ⅛ in. square, in various aluminium alloys, and the collets were made from ⅜ in. B.S.F. steel studding by drilling out the centre in a lathe and tapping with a No. 1 B.A. thread. This thread was found to be necessary, since if the collet was prepared with only a shoulder for restraining the specimen some deformation of the specimen occurred within the collet at high loads. The upsetting was carried out in a split die, accurately machined to restrain the gauge length of the rod during upsetting and to locate the collets at fixed positions on the rod, so that the same gauge length was obtained on all specimens. A section through the finished specimen is shown in Fig. 3. With the softer alloys upsetting was carried out cold but for the tougher materials the work was facilitated by heating the assembled die to a suitable temperature.

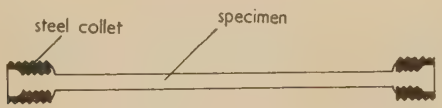


Fig. 3. Section through finished specimen

REFERENCES

(1) Andrade, E. N. da C. *Proc. Roy. Soc. A*, **84**, p. 1 (1910).
(2) Andrade, E. N. da C., and Chalmers, B. *Proc. Roy. Soc. A*, **138**, p. 348 (1932).
(3) Stanford, E. J. *The Creep of Metals and Alloys*, p. 8 (London: Temple Press, 1949).
(4) Guarnieri, G. J., and Yerkovich, L. A. *Proc. Amer. Soc. Test. Mat.*, **52**, p. 934 (1952).
(5) Lazan, B. J. *Proc. Amer. Soc. Test. Mat.*, **49**, p. 757 (1949).

Stabilization of air flow through a filter

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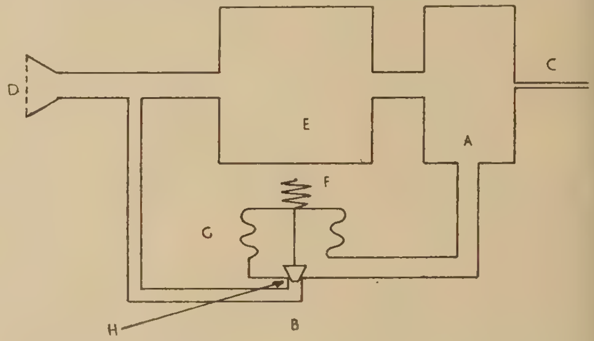
[*Note received* 20 *March*, 1958]

In connexion with the monitoring of airborne pollution, it often desirable to stabilize the air flow through a filter. Tw methods have previously been suggested:

(i) the inclusion of a "swamping" resistance to mal variations in filter resistance small in comparison wi the total resistance of the system*; and
(ii) the use of an adjustable throttle or air leak in th suction-line.†

The first method involves using a larger pump than otherwise necessary and the second method tends to b complicated. Very good stabilization can, however, b achieved by using the simple arrangement shown in th figure. The pressure in tank A builds up to the pressure which valve B opens, and the flow through the filter D the becomes equal to the constant mass flow through the aperture C. Valve B is a constant pressure valve of a type commonly used in refrigeration practice, and keeps the pressure in tank A effectively at a constant value above atmospheric pressure. This leads to a constant pressure fall across C, producing a constant mass flow through C.



Arrangement for stabilizing air flow through a filter

A, small pressure tank; *B*, constant pressure valve; *C*, small aperture; *D*, filter; *E*, suction pump; *F*, spring for adjusting valve *B*; *G*, bellows; *H*, small opening to inlet side of pump, making valve *B* substantially independent of variations in pressure behind the filter.

Full stabilization can be achieved by adjusting valve B to make the flow through C equal to the least flow which might be expected through the filter during sampling. This form of stabilization has been used with a small rotary vacuum pump model RB 4 (by Edwards High Vacuum Ltd.) in connexion with the monitoring of airborne dust radioactivity. A Danfoss constant pressure valve type JV [supplied by Dean and Wood (London) Ltd.], set to open at a pressure of about 4 lb/in.^{2}, has been used in conjunction with a tank of about 5 l. volume, and an opening to the atmosphere made by boring a 1 mm hole through a plug of 2 mm thickness. Variation of the pressure fall across the filter of between 0 and 300 mm of mercury has led to about 1–2% variation in the flow rate of about 20 l./s. Changes in flow due to temperature variations have been negligible.

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* D.S.I.R. *Atmospheric Pollution in Leicester*, pp. 133–134 (London: H.M.S.O., 1945).

† Perry, K. E. G. *The rapid detection and continuous monitoring of radioactive contamination on dust in laboratory air*, EL/R 1753, Section 5.3 (*b*) (Atomic Energy Research Establishment, 1955).

high-speed relay self-rectifying circuit for conductivity measurements

By D. M. G. Armstrong, B.Sc., A.R.I.C., Department of Physiology, Royal Veterinary College, London

[*Note first received* 5 *February, and in final form* 20 *March*, 1958]

double change-over action high-speed relay type 100Y Siemens Bros.) energized by a.c. from a filament trans-mer, and thus vibrating at double the mains frequency, sed to charge and discharge a capacitor through a Wheat-ne bridge conductivity network (Fig. 1). The other tongue

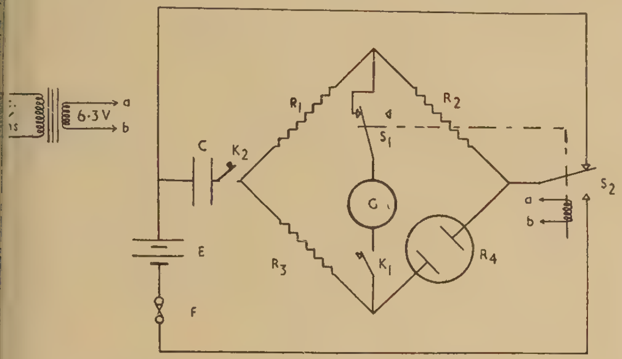

Fig. 1. High-speed relay self-rectifying circuit

R_1, R_2 = 1110 Ω ratio arm resistance boxes; R_3 = 11 110 Ω neasuring resistance; R_4 = conductivity cell, C = 4μF paper capacitor; E = 4V battery; F = fuse; G = moving coil galvanometer; K_1, K_2 = tapping keys; S_1, S_2 = relay change-over switches.

the relay is used to introduce a sensitive moving coil lvanometer in the bridge circuit during most of either the arge or discharge half of the cycle. The circuit has some nilarity with that of the secohmmeter of Ayrton and rry* in which a rotating commutator was used for the nultaneous reversal of the leads of both power supply and lvanometer.

For maximum current in the given conditions of the twork and for a reasonable synchronism in the action of

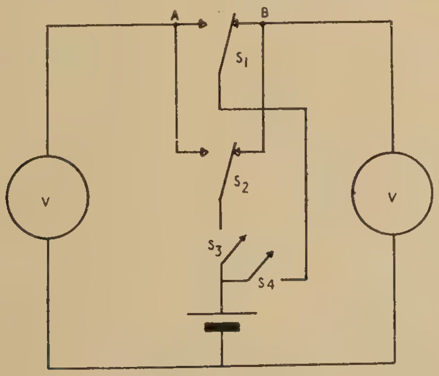

Fig. 2. Arrangement of relay in circuit

V, V = voltmeters; S_1, S_2 = relay change-over switches; S_3, S_4 = one-way switches.

ne two tongues of the relay, these must be adjusted to stay s long a time on one contact as on the other. This is done by placing the relay in circuit as in Fig. 2, altering the adjusting screws of the fixed contacts and tongues until the readings of the voltmeters, when connected to the battery *via* the contacts and one or other of the vibrating tongues, are approximately half the values read when connected directly to the battery. When adjusted, the relay should vibrate without contact bounce, a condition detected from the note emitted from the relay, and by the use of a cathode-ray oscilloscope, with the input leads connected to points A and B. A rubber band encircling the contact end of the relay damps out undue vibrations of the fixed contacts themselves and permits steady conditions to be obtained quite readily.

The sensitivity of this circuit is high; thus with an ordinary Post Office box and a galvanometer with a sensitivity of 24 mm/μA in circuit, a resistance of 100 000 Ω can be estimated to ±0·5% and one of 10 000 Ω to ±0·05%. The maximum mean current drawn with the given values of parameters in the circuit (Fig. 1) is 1·5 mA.

In testing this circuit, values of the cell constant of an Ostwald type of conductivity cell with platinized electrodes were obtained by measuring the conductivity of solutions of potassium chloride (from 0·001 to 0·05 N) and of hydrochloric acid (from 0·001 to 0·04 N) at 25·00° C. The standard deviation was ±0·75% of the mean value (0·65 cm^{-1}) for each type of solution. The mean value of the cell constant obtained with hydrochloric acid solution was 1% higher than that obtained with potassium chloride solutions, this difference being statistically significant, by Student's t test, at the 5% confidence level. On pooling the values obtained with both types of solutions, however, the standard deviation was only increased to ±0·9% of the average value of the cell constant. Thus it seems advisable to calibrate the cell with both a potassium chloride and a hydrochloric acid solution unless subsequent measurements are confined to the same type of solution (acid or neutral) as that used in calibration.

There was no significant change in the cell constant value on changing the ratio arm resistances from a 1 : 1 to a 10 : 1 ratio. There was a marked permanent polarization of the cell, after the introduction of each new solution in the cell, which could be greatly diminished by short circuiting the cell during the fifteen minutes required to raise the temperature of the cell and contents to that of the thermostat in which it was placed. The procedure for balancing the bridge was to press the galvanometer key K_1 permanently and to adjust R_3 until the galvanometer reading was the same for the on and off position of K_2; the value of R_3 obtained in this way remained the same on reversal of the leads of the conductivity cell.

The author wishes to record his thanks to Prof. E. C. Amoroso for his continued encouragement.

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* Ayrton, W. E., and Perry, J. *J. Soc. Teleg. Engrs lectricians*, **16**, p. 292 (1887).

A buckling spring calibrator for thread strength machines

By S. L. Anderson, M.Sc., F.Inst.P., Wool Industries Research Association, Leeds

[*Note received* 11 *March*, 1958]

It is often necessary to check the accuracy of machines for measuring the breaking tension of textile and other threads. The method of static calibration by hanging a series of known weights on to the loading grip is not completely satisfactory since any frictional and inertial forces are not exerted to the same extent as during an actual test when the loading conditions are dynamic. The ideal calibrating element would therefore consist of several threads of constant, known breaking tensions which can be used to check that readings given on the scale of the machine are correct. A calibrator which fulfils this ideal to a great extent has been devised, making use of the peculiar properties of steel strips of the kind used for expanding steel rulers, which have a curved cross-section.

Fig. 1 shows a diagram of the device. It consists of a horizontal plate with a block *B* at one end, to which is fixed one end of the steel strip 1·3 cm wide the concavity facing upwards. A wire hook *C* is linked to the free end of the strip and a smooth steel peg *D* projects from the frame immediately below *A*. In use the device is clamped at *E* in the loading grip of the strength testing machine and a length of thread or string is looped round the hook *C* and attached to the traversing grip of the strength machine. The machine is then started and when the tension exerted reaches a critical value the spring strip buckles to the position indicated by the dotted lines and registers on the strength machine in th same way as a breaking thread under test. The reading o the scale of the machine is then compared with the know buckling tension of the calibrator. Several elements wit differing buckling tensions are used to calibrate one machine

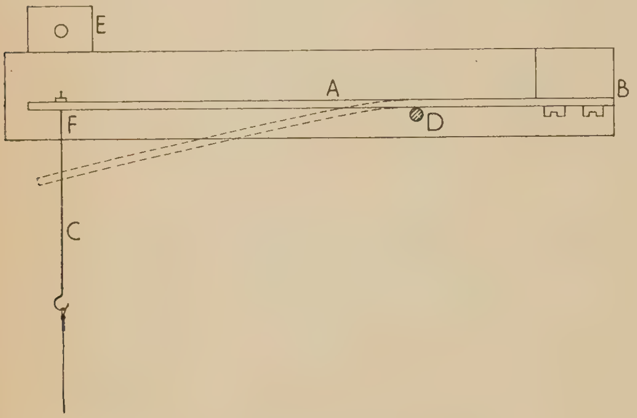


Fig. 1. Buckling spring calibrator

The tension *T* at which the spring buckles depends on th position of the peg *D* which acts as a fulcrum the produc of $T \times FD$ being approximately constant and equal t 1200 g cm for several constructed. The exact bucklin tension is determined once and for all by attaching a pan t the hook and progressively adding weights. Repeate bucklings took place at tensions which varied by less tha 1%. The buckling tension was not observed to change ove the range of extension rates 0·5 to 200 mm/min and sinc the effective weight of the strip is about 80 mg/cm its inertia effect is negligible for speeds and accelerations likely to b met with in tensile tests.

Fig. 2 shows a tension-extension relation for one of thes elements. On extension it is linear up to the region of th buckling tension at which it falls suddenly and further smal extension then takes place under a nearly constant lo tension. On retraction substantially the same relation i followed with a small amount of hysteresis. With the sprin rules available commercially it has been found possible t construct calibrators covering the range 50–480 g tension.

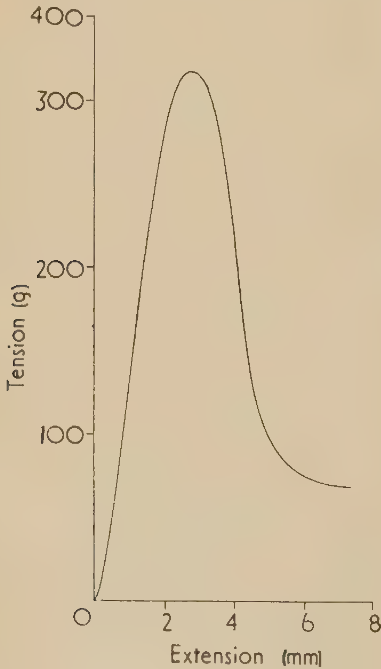


Fig. 2. Tension-extension relation

A neoprene vacuum gasket for wires

By A. C. Prior, B.A., B.Sc., Royal Radar Establishment,
Great Malvern, Worcs.

[*Note received* 1 *April*, 1958]

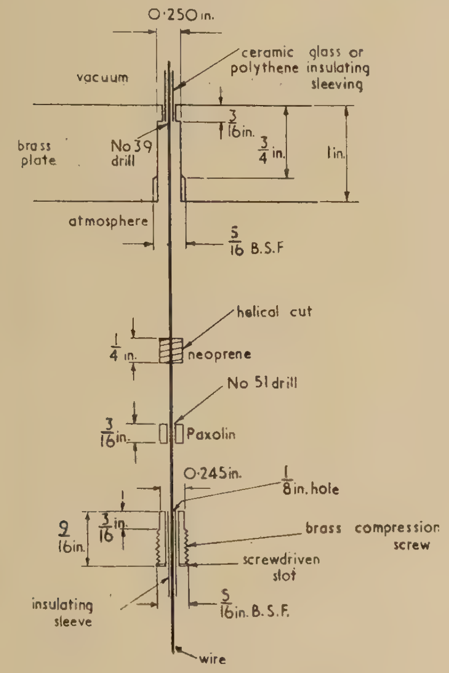
In a special vacuum furnace the need arose to take a large number of thermocouple wires through the metal walls. To reduce errors to a minimum, joints in the wires were to be avoided and, further, the wires had to be easy to remove and replace. The method employed depends upon the fac that an excellent vacuum seal can be obtained simply by the moderate compression of a suitable block of neoprene through which the wire passes.

The arrangement is shown in the figure. The neoprene consists of a ¼ in. length of ¼ in. diameter 75° shore hardness cord, cut off approximately square with a razor blade. For wires of diameter up to at least ½ mm, the central hole is made by forcing an ordinary sewing needle through. For larger diameter wires the hole should be drilled, for example after cooling in liquid nitrogen. The diameter is not critical a No. 58 drilled gasket is suitable for either 16 or 18 s.w.g. wire.

To enable thin wires to be readily inserted, a helical cut of pitch approximately $\frac{1}{16}$ in. is made with a razor blade from the outside to the centre of the neoprene while still on the needle. It is then possible to unwind the neoprene from the needle, and the wire can be threaded through the gasket by the inverse process, or by screwing the gasket on to the wire after making a 90° bend in the latter. The helical cut appears to have no detrimental effect on the vacuum tightness of the gasket; it has the further advantage that the same wire can be removed and replaced even after the ends have been enlarged by joining to another wire.

The Paxolin spacer (by Micanite and Insulators Co. Ltd.) is to prevent damage to the gasket by the twisting action of the compressing screw. The ¼ in. hole in the brass plate has always been finished with a square-ended drill, but this is bably not essential. None of the parts have to be made lose tolerances. A considerable reduction could be made he thickness of the plate by reducing the lengths of all components, probably including the neoprene. A uum seal is achieved with the screw only finger-tightened a $\frac{5}{16}$ in. diameter key, though much greater pressure s no damage.

large number of these assemblies can be packed into a ll area of plate. They can be used interchangeably for erent sized wires by using the appropriately drilled prene, and, if not required, can be blanked off with an drilled neoprene plug. They have been used with 0·013 d 0·020 in. diameter thermocouple wires, with copper ires of 18 and 16 s.w.g. carrying up to 8 A at 230 V 50 c/s, ith 1½ mm diameter thin-walled cupronickel tube for a nall cooling water system inside the furnace, and with a ·013 in. wire used for mechanism actuation by pulling rough the gasket under vacuum.



Gasket assembly

During the past four years several hundred have been nployed, mainly on metal systems pumped to 10^{-2}–0^{-4} mm of mercury with one- or two-stage rotary pumps, nd at no time has there been any evidence of leakage. ests have also been made on a system pumped to 10^{-6} mm f mercury by observing for changes in pressure, depending n whether the outside of the gasket was exposed to atmopheric pressure or a vacuum. It was estimated that a leak ate of 10^{-5} l.μ/s would have been detected but none was bserved. A needle-drilled gasket was tried without a wire assing through it; no leak was detected, indicating that nere is no lower limit to the diameter of wire that can be ealed.

It appears that these gaskets can be used on any system here the presence of metal and the exposed area of neoprene re not objectionable. The method could probably be dapted to a much larger range of wire diameters than has een tried to date, and is probably suitable also as a pressure eal.

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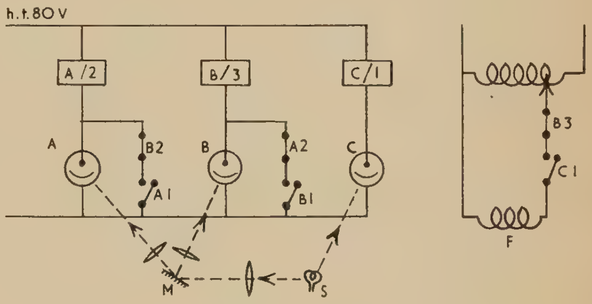
The use of germanium junction cells for photoelectric control circuits

By R. F. Peart, B.Sc., T. B. Rymer, M.A., Ph.D., F.Inst.P., and D. H. Tomlin, B.Sc., Ph.D., D.I.C.,
Physics Department, University of Reading

[*Note first received* 9 *April, and in final form* 12 *June,* 1958]

By using the recently available high sensitivity germanium junction photoelectric cells, we have constructed a simplified form of the well-known photoelectric system of controlling electrical circuits by means of the deflexions of a galvanometer arranged to give a null reading in a suitable balance network.

The essential simplification is that the germanium cells will conduct sufficiently at convenient levels of illumination to operate high resistance relays directly, without the need for electronic amplification. The relays used are of $10^5\ \Omega$ resistance and operate at a current threshold of $\frac{1}{2}$ mA. The circuit adopted is shown in the figure; the cells A and B are illuminated from the source S after reflexion from the galvanometer mirror M, and the corresponding relays $A/2$, $B/3$ switch the furnace current and also provide a locking mechanism to prevent loss of control if the light spot passes beyond the photocell. The third germanium cell C is continuously illuminated by the source, and together with its relay $C/1$ provides automatic cut-out of the furnace current in the event of lamp, or h.t. voltage failure.



Circuit diagram of temperature controller

A, B, C = germanium junction photocells type PG. 50A; $A/2$, $B/3$, $C/1$ = high resistance relays ($10^5\ \Omega$); $A.1$, $B.1$, $C.1$ = "make" contacts; $A.2$, $B.2$, $B.3$ = "break" contacts; S = 24 W lamp; M = galvanometer mirror; F = furnace winding.

(The optical system is shown only schematically and relay contacts are shown in positions corresponding to zero h.t. voltage.)

We have used this circuit in conjunction with a galvanometer of sensitivity 2 mm/μV at 10 cm, a potentiometer and a platinum/platinum–rhodium thermocouple to control the temperature of a furnace. The controller operates with a differential of ±13 μV or ±1° C, but there appears to be no reason why advantage should not be taken of the small size of the germanium cells to reduce the differential further if required, without using a more sensitive galvanometer.

We wish to thank Mr. K. Eccles for technical advice and assistance.

NOTES AND NEWS

Correspondence

Modifications to the collimating system of the Unicam 9 cm X-ray powder camera

The 9 cm diameter X-ray powder diffraction camera, manufactured by Messrs. Unicam Instruments Ltd., Cambridge, is in common use in this country and elsewhere. This camera was designed some ten years ago following the issue of a "user specification" by the X-ray Analysis Group of The Institute of Physics. The specification recommended a collimating system consisting of one defining slit only, the beam divergence being limited by this slit and by the focal spot of the X-ray tube; in this way, by choice of the angle at which the focal spot was "viewed" by the camera, a range of beam divergences could be obtained. It was felt that this arrangement, when used by skilled operators, provided the greatest possible flexibility of application of the camera.

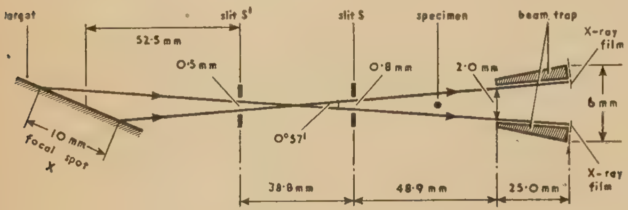


Fig. 1. Collimating system

Such an arrangement inherently requires a wider beam trap than is necessary in the majority of applications. The beam trap must accept the widest beam likely to be used in practice, and must also cater for a range of primary beam positions, because it is not possible to aline the camera so that the primary beam always passes precisely through the centre of the camera. A wide beam trap, in turn, limits the longest spacing which can be recorded; for the camera in question this is about 10 Å with CoKα radiation, equivalent to about 5° Bragg angle.

If the external width of the beam trap can be reduced, longer spacings can of course be recorded. For example, a distance of 9·0 mm between the outer edges of the beam trap enables spacings of 16 Å to be recorded with CoKα radiation; this improvement is important, for instance, in the mineralogical field, since the basal spacings of man important minerals, e.g. chlorites and montmorillonites, l in the range 10–16 Å. Several laboratories are believed t have made such a modification. So far as we are awar however, none of them has reported having done so in th literature; and it seems worthwhile to describe the modification recently carried out on the cameras in use at S.M.R.E as an indication of the extension to smaller Bragg angle that can typically be achieved in this way.

The new collimating system has been designed for a foca spot of dimensions 1 cm by 1 mm, on the assumption tha maximum angle of view of the focal spot of 3°20′ is to used; the existing slit S (Fig. 1), of width 0·80 mm, is supplemented by a further slit S', of width 0·50 mm, between and the X-ray tube focus X. These slits S and S' now determine the maximum angle of divergence of the primary bea equal to 57′, and completely define the path of the bea through the camera. Somewhat finer scatter slits are no used. A new beam trap and backplate have been constructed the beam trap accepts the whole of the primary beam a defined by the new slit system. With an angle of view large than 3°20′ some of the focal spot is unable to enter th camera. For angles of view smaller than 3°20′ the bea divergence is limited by the focal spot size and slit S; slit S now has no effect, and in this case the arrangement is simila to that of the original collimating system.

With the modified camera, reflexions at $\theta = 2°30'$ (20 Å with CoKα radiation) have been recorded. Fig. 2 show two films of a cylindrical specimen, 0·16 mm in diameter of Delabole slate; film (*a*) was obtained with the unmodified camera, film (*b*) with the new collimating system and with th same exposure as (*a*).

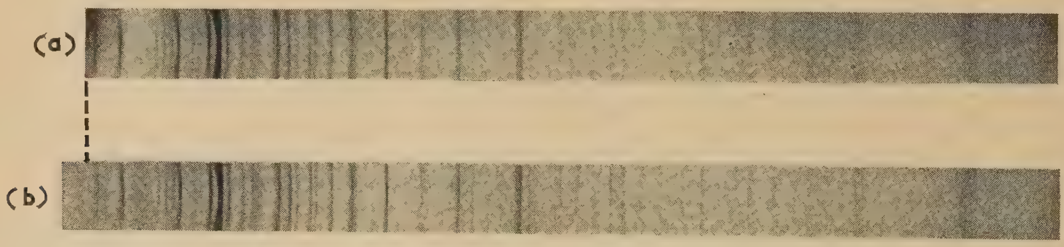


Fig. 2. X-ray diffraction patterns of Delabole slate

(*a*) With original camera; (*b*) with modified camera

We wish to acknowledge helpful discussions with Mr H. P. Rooksby and Dr. E. G. Steward of the Research Laboratories of The General Electric Company Ltd., Wembley. This note is published by permission of the Ministry of Power.

Safety in Mines Research Establishment
Sheffield, 1

R. L. Gordon
O. G. Griffin
E. P. Rodgers

[19 March, 1958]

corrosion proof vacuum controller for pressures under 1 mm of mercury

the course of a recent investigation, the need arose for a cuum controller capable of handling corrosive gases, their essure varying between 0·01 to 1 mm of mercury. None the existing vacuum controllers could be adapted for this urpose; either their leak-valves were not suitable for an -glass construction, or else the pressure-sensitive element g. Pirani gauge) could not withstand the corrosion. In me cases, the all-glass construction was feasible, but the sting regulation was not as sensitive as desired.

If a reliable and sensitive vacuum control at 0·01 mm of ercury pressure was to be maintained, some sort of power mplification between manometer and leak-valve had to be ed. It seemed that the most versatile method of amplifican between the pressure sensitive element and the pressuregulating device could be an electrical one, consisting of an mplifier and a servomotor. The use of such an amplification ain makes a continuously working leak-valve with strictly ear characteristic very desirable, if not absolutely necessary. the needle valves in use, the gas flow is not a linear function the needle displacement. From the point of view of rrosion resistance, only the U-tube manometer filled with icone oil could be considered. To obtain the desired nsitivity, the inclined Toepler arrangement was used. The nsitivity was further increased by optical projection of the eniscus image. As the leak-valve had to be an all-glass onstruction and linear in behaviour, a ground glass tube, ted with a glass rod of very close tolerance, was used. he annular space between the tube and rod serves as the ak-valve, the flow being controlled by the length of the rod troduction into the tube.

The general arrangement of the components may be seen om Fig. 1. A simple projection system, in fact a commercial slide projector for 2 × 2 in. slides, projects the image of the liquid level (silicone oil No. 703 coloured with some Sudan III) of the manometer on a gas-filled photocell with twin cathodes (No. 920). An optical amplification of 0 to 100 times was possible with this arrangement. A relay amplification system is then used. The signal output from the photocell cathodes controls a twin triode (12AT7) between cut-off and conduction, so that the sensitive relays connected to the anodes of the triode are either energized or not. The task of the sensitive relays is to control a polarized relay with three positions (centre off), whose contacts connect 24 V a.c. to a reversible servomotor.

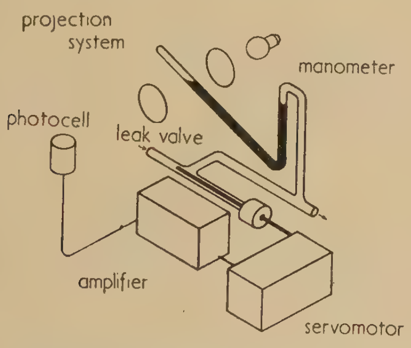


Fig. 1. The general arrangement of the vacuum controller

The servomotor inserts a longer or shorter part of the rod into the tube of the leak-valve, thus reducing or augmenting the leak accordingly. The construction of the leak-valve can be seen in Fig. 2. In its simplest realizable form, the leak-valve is made of a KPG glass tube (by Schott and Gen., Mainz) of 10·00 mm inner diameter and its moving part is a KPG glass rod, ground and polished to within 9·99 mm diameter. When the above tolerances are realized, at a pressure difference of one atmosphere, the leak through the valve, V, will be of the order $V \simeq \frac{50}{l}$ mm^3/s at N.T.P., where l is the active length of the regulating element.

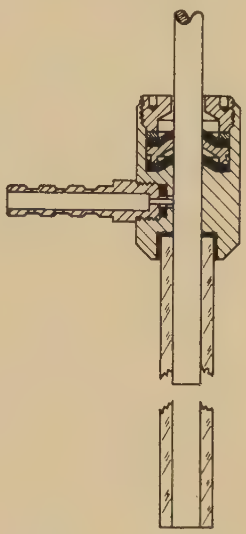


Fig. 2. The construction of the leak-valve. The inlet of gas can also be made through a *T*-piece in the glass tubing and the lower neoprene disk of the Wilson-seal seated in direct contact with the glass

In a glass system of about one litre volume, continuously pumped by Speedivac 1S50 single stage rotary pump (by W. G. Edwards and Co. Ltd.), any pressure between 0·1 and 1 mm of mercury could be maintained indefinitely, with oscillations not exceeding 0·01 mm of mercury. The response time of the system is identical with that of the oil-filled manometer.

Thanks are due to Mr. M. Mokady, who contributed materially in various stages of the construction of the described apparatus.

Scientific Department
Israel Ministry of Defence
Tel-Aviv
Israel

I. Amariglio
M. M. Benarie

[28 March, 1958]

New books

Logical design of digital computers. By M. PHISTER, Jr. (New York: John Wiley and Sons Inc.; London: Chapman and Hall Ltd., 1958.) Pp. xvi + 408. Price 84*s*.

The subject of logical design of computers is intended, in the words of the author (p. 11), "to fill the void lying between the systems analysis, which describes the problem [to be tackled by the computer] and the circuit components which must be connected together to solve it." Primarily, therefore, it concerns the structure of the machine control and the arrangement of the arithmetic facilities provided. In order to appreciate the problems involved it is necessary to engage in a good deal of description of the various parts of the machine, and this is done in Chapter 7 (Digital computer memories) and Chapter 8 (Input-output equipment) in a satisfactory, though not wholly comprehensive manner. To deal with the logical properties of these units and to allow a mathematical treatment to be given of the structure of the arithmetic section in Chapter 9, a very full treatment of Boolean algebra and its application in this context is given in Chapters 3, 4, 5 and 6. An introductory chapter (2) on circuit elements, a necessary chapter on checking (10), the vital chapter on the control unit (11) and a miscellany of practical advice (Chapter 12) complete this interesting book.

There are a few surprising omissions, such as the lack of a treatment of "floating point" arithmetic, and the omission of a detailed discussion of the structure of instruction codes. However, the general treatment follows a logical sequence, is readably written, has a very comprehensive bibliography appended to each chapter and includes useful sets of exercises. The emphasis on Boolean algebraic methods helps to give a unified treatment of the subject, but also obscures some of the real interest of the subject. Reverting to the author's own definition it is obvious that the logical designer must reconcile the demands of the systems analyst and of the engineer for consideration. This reconciliation is more an art than a science, although the designer will often make use of the many useful techniques described.

The artistic element, the nice balance of opposed arguments, is given no place in the book. The result is a trifle dry for my taste, but a vintage wine none the less.

A. S. DOUGLAS

Präzisionsmessungen von Kapazitäten, Induktivitäten und Zeitkonstanten. Band I: Kapazitäten. Band II: Induktivitäten und Zeitkonstanten. By E. BLECHSCHMIDT. (Braunschweig: Friedr. Vieweg & Sohn, 1956 and 1957.) Pp. 166. Price DM.11.80 each vol.

These two volumes, dealing with the precision measurement of capacitance, inductance and time-constant provide information for carrying out the measurements, and the treatment is essentially practical rather than theoretical. Consideration in some detail is given to many matters which concern precise electrical measurements, and in a few instances there is rather too much space devoted to detail: for example, formulae for calculating the inductance of circuits occupy twenty-one pages. On the other hand the subject of time-constants is dismissed in only ten pages.

Two-thirds of each book is devoted to the methods of measurement, and, amongst these, bridge methods predominate. These sections include much information that is required by anyone concerned with electrical measurement, but there is, in parts, a lack of the finer points which m be appreciated in precision measurements. Thus the standa balance equations are given for a large number of bridg but the effects of the residual parameters and second-or terms are included in only a few instances. The part time-constants is particularly weakened by this omission.

At the end of each volume there is an extensive bibl graphy (20 pp.) of papers with their titles.

In conclusion, it may be said, that these volumes wou be a reliable guide to the art of precision measureme provided that reference is made to the appropriate origi papers when necessary.

G. H. RAYNER

Communications and electronics buyers' guide, who's who a reference book, 1958–9. Edited by C. C. GEE. (Londo Heywood and Co., 1958.) Pp. viii + 360. Price £5

For an industry which is continually growing, as is t British electronics industry, it becomes more difficult to kn which firms make a certain product and to be able to kn where to buy an instrument or component. From time time several of the trade associations have made their o lists as they apply to their own membership. Now t publishers of this volume have undertaken a huge task endeavouring to cover the electronics industry in all its aspe Let it be said at once that they have made a good job of This is, of course, not a book for an individual to buy b its cost will quickly be repaid for any organization or esta lishment dealing with the purchase of equipment or advising on the availability of any equipment.

In addition to the buyers' guide there are sections givi information on professional, trade and research association universities, technical colleges and educational adviso councils; who's who; and a reference section. In this the is a large number of product surveys, comparing the spec fications for particular products of the various man facturers; industry statistics; glossary of abbreviation standards and specifications; colour codes; frequen allocations; radio and television broadcasting; technic journals.

A. J. MADDOCK

Messen und Regeln in der Chemischen Technik. By HENGSTENBERG, B. STURM and O. WINKLER. (Berli Springer-Verlag, 1957.) Pp. xix + 1261. Price DM.146

The instrumentation and control of chemical plants ha developed very rapidly in the past decade or two, and ther are now many examples of fully automatic plants. Muc that has been learnt about automation in connexion wit chemical plants has applications in a wider field, and instrument engineers, both those concerned with chemical plant and process engineers generally will therefore welcome th publication of this new book, which deals exhaustively wit the subject of measurement and control in the chemica industries.

The authors have prepared the book as a work of reference Each chapter includes a statement of the basic principles o the method, a detailed description of the measuring techniques used, and a discussion of the various aspects of th performance obtainable with reference to the proprietar instruments available where these have established themselve for particular applications. There are separate chapters o all the usual physical measurements, e.g. temperature pressure, density, flow, viscosity, pH, etc., and in all case methods are discussed applicable to continuous flow con ions. Some of the later chapters deal with the problems using the information from the measurement of the ysical quantities to control the chemical process used in plant, and detailed descriptions are included of the rious types of controller available. There is also a great al of useful data about the presentation of information d the layout of the plant to achieve the most satisfactory erating conditions. Altogether the book is a real source information of the principles and practice of chemical ant instrumentation and can be strongly recommended as work of reference.

There are a number of omissions. Firstly, bearing in mind e importance of data processing in the chemical plant dustry, the reviewer would have liked to see a fuller reference to this subject with detailed descriptions of the various mputers which are now beginning to find their way into ur instrumentation systems. The reviewer was also surprised see so little reference to the use of methods employing dioactive substances to the measurement of physical antities in the process industries (e.g. thickness, density, ow, etc.). Nuclear techniques offer unique methods of aling with some of these problems and a fuller reference in e book to these techniques would have made it more luable.

The book is well printed and illustrated and will be a luable addition to the bookshelf of anyone concerned or anting to be concerned with instrumentation in the process dustries. D. Taylor

he performance of metal-cutting tools. By R. Tourret. (London: Butterworths Scientific Publications, 1958.) Pp. xii + 184. Price 50*s*.

t is rather surprising that the fundamental engineering peration of metal cutting has received relatively little basic cientific study, and that no satisfactory theories have been stablished. In spite of the apparent simplicity of the echanics involved empirical methods are followed in almost ll developments in this field. The author of this book has ade a brave effort to collect and correlate the results of any isolated investigations with the object of pointing the way for further studies but it appears that the subject is nsufficiently developed for the correlation to be successfully chieved. The result, therefore, tends to be a collection of ometimes contradictory data. The book makes no claim to e a workshop manual and its principal value would seem o be as an extended bibliography for those planning to enter his field of study. W. Betteridge

An introduction to transistor circuits. By E. H. Cooke-Yarborough. (New York: Interscience Publishers Inc.; Edinburgh: Oliver and Boyd Ltd., in collaboration with the United Kingdom Atomic Energy Authority, 1957.) Pp. xii + 154. Price 15*s*.

The author states in his preface to this book that it is concerned mainly with the use of the non-linear properties of transistors. Within this limitation, the book can be recommended as a good introduction to transistor circuitry.

In Chapter 1 a satisfactory physical picture is built up of the mechanism whereby the semiconducting properties of germanium are used to obtain amplification. In Chapter 2 expressions are derived for the low frequency parameters of the three possible circuit configurations. Chapters 4 and 5 give a very good summary of pulse and switching circuitry.

This reviewer found the circuit diagrams hard to follow for whatever their purpose they are always drawn with the positive potential at the top of the page. There is a need for a Bainbridge-Bell* in the transistor world.

I. J. Richmond

Instrumental methods of analysis. 3rd ed. By H. H. Willard, L. L. Merritt and J. A. Dean. (London: D. van Nostrand Co. Ltd., 1958.) Pp. vi + 626. Price 56*s*. 6*d*.

The third edition of this book differs considerably from the previous editions. Almost all the chapters in the second edition have been rewritten and new ones on flame photometry, infra-red and fluorescence methods, etc., have been added. An attempt has been made to cover a tremendous amount of ground in 626 pages and the 23 chapters include descriptions of, for example, colorimetry, fluorescence methods, turbidimetry, U.V. visible, infra-red and mass spectrometry, emission and raman spectrography, flame photometry, X-ray methods, refractometry, polarimetry, thermal conductivity and gas chromatography, radioactivity, nuclear magnetic resonance spectroscopy, potentiometric titration methods, pH measurement, electrodeposition, coulometry, polarography, amperometric titrations, conductance methods and enthalpy titrations.

The layout of each chapter is on the same general lines, for example, in the case of polarimetry, there is a description of the theoretical basis of the subject, the principles of polarimetric instruments, operating instructions supplied with a particular polarimeter and two practical problems dealing with the application of the instrument for the determination of specific rotation and the concentration of a given solution. Finally there are a few questions and problems.

It would appear that this book forms the basis of instructional courses in America on instrumental methods of analysis. If this is the purpose of the book then it is doubtful whether it has been achieved. Almost all the instruments in the 350 illustrations are American ones and references to the literature show a similar bias. By perusing this book British readers will learn a great deal about the instruments available in America for analytical tests. The reviewer feels, however, that in its way the publication of this volume draws attention to the real need, i.e. for a similar book with a much more fundamental approach to the subject and with much less information about proprietary instruments. J. Haslam

Electronic measuring instruments. 2nd ed. By E. H. W. Banner. (London: Chapman and Hall Ltd., 1958.) Pp. xvi + 496. Price 56*s*.

My review, in this *Journal*, of the first edition of this book considered that it was somewhat in the nature of a descriptive catalogue of measuring instruments employing electronic devices. The instruments described are commercially available and the descriptions in some of the sections centre around a particular manufacturer's products.

The pattern is continued in this second edition in which one hundred pages have been added. The increase is primarily to incorporate descriptions of further instruments or of instrument types not before included. In these might be mentioned valve voltmeters, phase-measuring instruments, absorptiometers, spectrometers, electronic gauges for metrology, recorders, etc. A. J. Maddock

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* The pioneering work and constant vigilance of the late Mr. Bainbridge-Bell contributed greatly to the clarity of electronic circuit diagrams and nomenclature—Ed.

New instruments, materials and tools

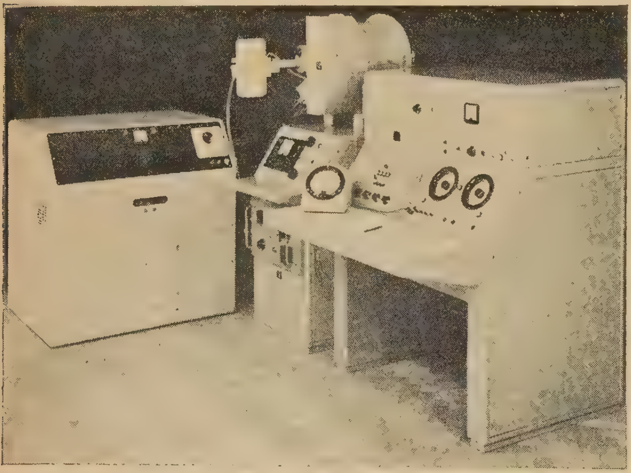
The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improv products. The Institute of Physics assumes no responsibility for the statements given below: information for these has be taken from literature supplied.

Electroplating tin and lead. Dalic Metachemical Ltd., 121 Judge Road, Toronto 18, Ontario, Canada.

The Dalic process of plating uses a hand operated graphited stylus wrapped in cotton-wool and saturated in the plating solution. A low voltage supply is connected to the work to be plated by a cathode lead and to the stylus. The stylus is moved over the surface of the work. Most metals may be deposited and two special solutions have now been introduced for the deposition of tin and lead either singly or as a tin-lead alloy.

Fluorite polychromator. Hilger and Watts Ltd., 98 St. Pancras Way, London, N.W.1.

The fluorite polychromator is an automatic spectrograph for the analysis of carbon, phosphorus, and sulphur, in steel. The most suitable spectral lines of these elements are in the far ultra-violet region, for which reason the spectrograph has fluorite optics housed in a vacuum chamber, so avoiding the absorption of quartz or glass and of the oxygen in the air. The complete equipment consists of a specially redesigned version of the Hilger B.N.F. source unit, discharge chambers for flat and rod samples, the spectrograph itself, the pumping apparatus, and the electronic controlling and measuring instruments. Its fundamental principle is the same as that of other polychromators by this firm. The spectral lines of the chosen elements are passed by exit slits to photomultipliers, whose outputs are stored in capacitors. The potentials of the capacitors are subsequently measured and the measurements interpreted by calibration graphs.



Fluorite polychromator. On the left is the source unit and, immediately to its right, the cabinet housing the pumping equipment. This cabinet supports the vacuum chamber of the spectrograph, from which projects the sparking chamber for the samples. On the right is the electronic console arranged as a desk for the operator. The large meter standing on the shelf gives the results.

So far, the instrument has been tested in analysing plain carbon steels and low-alloy steels, and most of the samples have had the three relevant elements in the following co centration ranges:

Carbon	0·1–1·7%
Phosphorus	0·005–0·1%
Sulphur	0·005–0·06%

Some samples with carbon contents up to 4%, phosphor contents up to 1·8%, and sulphur contents up to 0·2 have also been examined, and the results are said to indica that even higher concentrations could be dealt with sati factorily by the instrument.

An idea of the precision attainable can be gained from th typical results listed in the following table:

Element	*Concentration* %	*Standard deviation* ±
Carbon	0·04	0·001
	0·08	0·002
	0·20	0·006
	0·50	0·008
	1·5	0·02
Phosphorus	0·010	0·001
	0·025	0·002
	0·050	0·003
Sulphur	0·02	0·001
	0·04	0·002

The total time taken by a complete analysis, including a stages from the mounting of the sample to the final inte pretation of the results, is about a minute and a half, whic compares favourably with the time that would be require by wet chemical methods. The precision of the carbo determinations almost certainly exceeds that of routin chemical methods.

Cathode-ray tube for battery operation. Electronic Tube Ltd., High Wycombe, Buckinghamshire.

The 3ANP1 $2\frac{3}{4}$ in. diameter tube has been specially designe for use in battery operated equipment, where power con sumption must be kept to a minimum. The cathode heate consumption is only 400 mA at 2·5 V, and the anode potentia can be in the range 800 to 1500 V. Electrostatic focusing i employed, and the electrostatic deflexion can be eithe symmetrical or asymmetrical. The tube can be supplied wit either a P1 or a P7 phosphor. With an anode potential o 1 kV, the *X* and *Y* plate sensitivities are 20 and 11·5 V/c respectively.

Scintillation crystals. Levinthal Electronic Products, Inc Nuclear Division, Stanford Industrial Park, Palo Alto California, U.S.A.

Thallium-activated sodium-iodide crystals, grown in ingot 5 in. in diameter × 4 in. long plus a 90° conical end, can b supplied in any sizes and configurations derivable from thi shape. Cylinders, cylinders with truncated conical ends, an cylinders with re-entrant end-wells can be supplied eithe unmounted, enclosed in standard mounts, or specially mounted to individual requirements.

ı the production of these crystals, special attention is ned to have been given to the attainment of the highest sible optical quality and uniform distribution of thallium insure response to γ-rays uniformly throughout the tal volume.

ı addition to the raw forms described, these crystals are available in high-resolution γ-ray transducers consisting , 3 and 5 in. crystals integrally mounted with appropriate tomultiplier tubes and enclosed in shielded housings ing built-in preamplifiers.

meter test set. A. M. Lock and Co. Ltd., 79 Union Street, Oldham, Lancashire.

s pH meter test set consists basically of a long life dry cell oss which is connected a number of high stability resistors ning a potentiometer. A switch selects 6 pre-set voltages, interval between each being approximately equivalent to H units. A number of interconnecting leads are provided connecting to the pH meter under test. Two output nexions to the test set are provided, a low impedance and a high impedance one of approximately 250 MΩ to ulate the high resistance of normal glass electrodes.

ctronic hygrometer. J. L. Shaw Electronics Ltd., 31 Market Street, Bradford, Yorkshire.

is instrument uses as detecting element a capacitor with a groscopic dielectric a few microns thick with gold electrodes. e detector is contained in a fine wire gauze protector, and gs into a coaxial cable connecting it to the meter. The ecting element is 1 cm diameter and 6 cm long. The tector can be used with any length of cable. The instru- ent can be checked by inserting the detector in a standardiz- g jar provided and adjusting the meter by pre-set controls. ie meter has a linear scale and is stated to have a response ne of a few seconds with good long-term stability and gligible temperature error and hysteresis.

Electronic hygrometer

ultiplier unit for analogue computers. Solartron Electronic Group Ltd., Thames Ditton, Surrey.

he TA 721 multiplier is designed round the multiplier tube 0 CAX. This has an electron gun, *X* and *Y* deflector ates like an ordinary cathode-ray tube, but in place of the reen there are two disk electrodes mounted one behind the her. The electrode nearest the gun has a horizontal slit it. The portions of the beam current intercepted by the o disks form the inputs to a differential amplifier which rives the *Y* plates. The cathode-ray beam is thus constrained to remain on the edge of the slit in the first disk. If an *X* deflexion voltage is applied, the spot will move horizontally across the tube following the slot. If now an axial magnetic field is generated in the tube, the spot will tend to be deflected vertically as a result of the lateral velocity of the beam and the axial field. The servo amplifier constrains the spot to follow the edge of the slit, and the voltage applied to the *Y* plates to do this can be shown to be the product of the voltage on the *X* plates and the current producing the axial magnetic field. The *X* plates are driven symmetrically by an amplifier which will accept a signal of up to ±100 V single ended, and the coil is driven by a further amplifier with multiple feedback loops which also accepts a signal of up to ±100 V single ended. The output voltage of up to ±100 V is taken from the servo amplifier *via* an output amplifier. The output voltage is 0·01 × (input 1) × (input 2). It is claimed that up to 1 kc/s the gain of the amplifiers varies by less than 1% and the phase shift is less than 1°. The overall error is stated to be less than 1% of the maximum input.

Cable fault locator. H. Tinsley and Co. Ltd., Werndee Hall, South Norwood, London, S.E.25.

The type 5335 locator utilizes a conventional Wheatstone bridge circuit in which the two sections of the faulted conductor, one on each side of the fault, comprise the two external arms of the bridge. The other two arms are contained within the instrument. By the use of a detector with a high input resistance, it is possible to locate high resistance faults without loss of sensitivity. It is claimed that faults having resistances from zero to 200 MΩ in dielectrics such as rubber, and higher in the case of polythene, can be located within $\frac{1}{2}$%. A guard terminal is provided so that the effect of surface leakage on accuracy may be eliminated, and in extreme cases corrections for internal cable leakage may be applied. Coarse and fine controls are provided for the initial balance of the bridge under shorted input conditions. The bridge is balanced under measuring conditions by adjustment of a precision potentiometer having a total travel of 10 turns. Indication is on a robust pointer meter.

High impedance recorder. Sunvic Controls Ltd., 10 Essex Street, London, W.C.2.

A new potentiometric type of recorder has been designed for recording d.c. potentials of 0/100 mV across an impedance not exceeding 10 MΩ. Eight ranges are available, which can be altered by plug-in bobbins. The recorder is stated to have a calibration accuracy of 0·5% and a sensitivity of from 0·1 to 0·25%, depending on the source impedance. A constant current supply, with a stability of 0·1% is incorporated for energizing the measuring bridge circuit. There are 12 chart speeds between 1 and 45 in./h; the response time is about 2 s. High and low level alarm contacts, retransmitting slide-wire, or a 300° shaft digitizer can be fitted. Range change and backing-off units are available for use with recorders monitoring ionization current. The range unit comprises a multi-point switch for selecting three independently adjustable values of resistance; these are normally calibrated to give three decade ranges. The backing-off unit comprises a Kelvin–Varley potentiometer, compensated to give a linearity of 0·2%, and a constant supply unit. It enables a standing ionization current to be backed off so that the recorder shows deviations from a desired value.

High-speed electric recorder. Sierex Ltd., 241 Tottenham Court Road, London, W.1.

A recorder of novel construction, manufactured by Elema–Schönander in Sweden has recently been announced. The device, known as the Mingograf 230B, consists essentially of a taut-suspension galvanometer operated by an amplifier. In place of the usual pointer or mirror, the galvanometer movement carries a fine glass nozzle of approximately 10 μ diameter. By means of a vibrating membrane pump, a special writing fluid is forced at high velocity through the tube. The resulting liquid jet impinges on the recording paper, which may be at a distance of up to 60 mm. The liquid jet thus constitutes the galvanometer "pointer"; however, since it is not an integral part of the mechanical system, the liquid jet does not contribute to the moment of inertia. The galvanometer movement therefore has a high resonant frequency (about 650 c/s). The amplifier is provided with compensation circuits so that the response curve is practically flat from 0–500 c/s. Over the same frequency range, the phase shift is less than 5 deg. From 500–1000 c/s the response falls by a factor of about 3 and the phase shift rises to about 30 deg. In addition to amplitude and phase correction, the amplifier circuits also provide a linearity correction.

The amplifier-galvanometer system has an overall sensitivity adjustable from 0·2 mm/mV to 0·04 mm/V, the input impedance being 1 MΩ (asymmetrical) or 2 MΩ (symmetrical). The maximum useable deflexion is determined by the dynamics of the liquid jet, and depends on the nozzle-paper distance (which can be 20, 40 or 60 mm) and the frequency: it varies from 5–75 mm. The response is claimed to be linear to between 2 and 4%. Six paper speeds from 5 to 200 mm/s are available, and the magazine holds a roll 70 m in length. A useful refinement is the provision of an electrical zero-shift control.

Pocket radiation monitor. Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

The type PW 4014 meter employs transistors and printed wiring in order to reduce bulk. It is a watertight, fully tropicalized instrument of rugged construction designed for the general survey, location and measurement of radioactivity. It weighs only 1 lb 5 oz, and its small dimensions ($6\frac{1}{8} \times 4 \times 1\frac{3}{8}$ in.) enable it to be carried easily in the pocket. A built-in Geiger counter permits the instrument to be used as a probe for measuring γ-radiation and a separate mica end-window Geiger counter with a flexible lead can be plugged into the instrument for β-ray measurements. The instrument has 3 and 30 mr/h ranges and is direct reading in mr/h. A small earphone can be connected for the audible detection of very low intensities. The power supply is a 3 V flashlamp battery, or two small 1·5 V cells. The transistor circuit has a low current drain, so that long battery life is assured.

Indicator tube for computer circuits. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

The DM160 indicator is a triode vacuum tube in which the anode serves as a fluorescent screen giving a rectangular blue-green glow some 20 mm^2 in area. A grid voltage swing of only 3 V is required to extinguish the screen glow, and owing to the high input resistance of 100 kΩ the tube is said to have negligible effect on the characteristics of the circuit to which it is connected. With an anode voltage of 50 V, the anode current at maximum light output is 0·5 mA, falling to 5 μA at cut-off. The small size of the unit 5 mm diameter T1 bulb with flying leads) enables it to incorporated readily in small, closely stacked repetitive up

General-purpose oscilloscope. E.M.I. Electronics L Hayes, Middlesex.

The type WM7 oscilloscope is constructed of plug-in u and is intended both for general laboratory work and more specialized work such as radar, television and hi speed oscillography. A Y-amplifier unit giving a vert sensitivity of 100 mV/cm has a response level to 3 dB fr zero to 50 Mc/s. An alternative dual channel beam-swi unit has a bandwidth from zero to 25 Mc/s with a verti sensitivity of 50 mV/cm. A useful facility is a push-butt control which acts so that if the spot is deflected off screen, depression of the button causes the beam to confined within a limited area of the screen, thus enabl the display to be easily centralized by the normal sl controls. The instrument uses a 5 in. high-sensitivity t with an accelerating potential of 10 kV. The tube is fit with a specially illuminated reflecting filter and graticule eliminate parallax error. Two time-bases are built into unit, giving normal and delayed sweeps. The normal swe speed is continuously variable over a range from 12·5 m to 0·5 s per cm. An accuracy of 2% is claimed for time a voltage measurements under all conditions of expansi High accuracy measurements can be made rapidly eithe direct readings from dials, or by measurement of the s deflexion using the no-parallax graticule.

Portable X-ray dosemeter. Electronic Instruments Lt Lower Mortlake Road, Richmond, Surrey.

The model 37A dosemeter consists of a robust, di reading, battery-operated valve electrometer, mount complete with ion chamber polarizing supply and a range input capacitors and resistors in a steel case. All the hig insulation components, including the electrometer valve, a mounted in a lead-lined screening box to reduce errors d to scattered X-rays. About $\frac{3}{32}$ in. of lead is bonded to st sheet in the construction of this box. The instrument case sealed and desiccated. Five input capacitors are fitte These, in conjunction with a range switch which controls t full-scale voltage sensitivity of the amplifier from 0·3 10 V, provide 12 dose ranges from 0·45 mr to 150 r. T controls are so arranged that, except on the highest a lowest dose range, it is possible to reduce the sensitivity adjustment of the voltage control during the course of a ru without disturbing the stored charge on the capacitor. Th facility is convenient if the dose being measured shou prove to be larger than was anticipated at the commenceme of the run. Three input resistors are fitted which, in co junction with the voltage range switch, give 12 *dose-ra* ranges from 0·045 mr/s to 15 r/s. The ranges quoted abo apply to a chamber of from 33·3 to 40 cm^3 volume; internal control is provided to adjust for variation of chamb volume over this range. The chamber polarizing supply provided by a 300 V miniature battery of the type used portable electronic flash equipment; other batteries are the "deaf-aid" type. All batteries can be checked agai the internal meter. The instrument has a design centre fee back factor of more than 100, the whole of which is used degenerate input cable capacitance and improve the inp insulation resistance. The feedback voltage is brought o to a pair of sockets at the rear, so that the instrument ca be used as a high input resistance voltage amplifier with gain of unity.

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

ater deionizer. Griffin and George Ltd., Ealing Road, rton, Wembley, Middlesex. Leaflet P2007/5706 describes B.D.H. water deionizer for laboratory use which is a venient all-glass apparatus, compact, and easy to use. he use of a metal stand it can be attached to a wall, or l to a bench, where it occupies less than one square foot pace.

lelting practice for the production of aluminium alloy ings. Alar Ltd., 3 Albemarle Street, London, W.1. A sed edition of an illustrated 52-page booklet explains in ple terms the melting and preparation of aluminium alloys o the castings stage. The booklet deals only with practical siderations and is not intended to be comprehensive. It uld, however, be useful in the instruction of non-technical ndary workers.

rinciples of microradiography. Philips Electronics Inc., South Fulton Avenue, Mount Vernon, New York, .A. A 48-page book gives a bibliography prepared by tman Kodak Research Laboratories on the subject of roradiography and soft X-ray radiography. Other subjects ered include: definition, geometrical blurring, film unrpness, unsharpness due to movement, contrast, soft ay, increasing contrast in the specimen, increasing contrast h photographic material.

Vire temperature indicator. Addison Electric Co. Ltd., 12 Bosworth Road, London, W.10. A leaflet gives ails of the type 425 portable wire temperature indicator. is instrument has been specifically designed for the rapid asurement, during production, of the temperature of preated copper conductors before these enter an extrusion chine.

Epoxy resins. Aero Research Ltd., Duxford, Cambridge. number of well-produced brochures give details of the use Araldite resins for a wide range of purposes, including ir use in the electrical industry, for surface coating, nding, casting, tooling and in glass cloth laminates.

Electronic measuring instruments. Marconi Instruments d., St. Albans, Hertfordshire. A 300-page catalogue gives tails of telecommunication measurement equipment and dustrial electronic instruments. The catalogue is fully strated and has a useful 10-page index.

Polarized relay. Telephone Manufacturing Co. Ltd., ollingsworth Works, Martell Road, West Dulwich, London, E.21. Leaflet F3526/5H gives details of the type 51 Carnter polarized relay. The relay incorporates an improved mature suspension and a facility for magnetic adjustment.

Photostress. L. Brooke Edwards, Esq., 25 Palmeira venue, Hove 3, Sussex, England. A pamphlet describes e technique of Photostress. This has been developed in e United States, and is a means for converting strain into lour. It is essentially a "reflexion" photoelastic technique.

Air diffusers. Anemostat (Scotland) Ltd., 220 West Regent reet, Glasgow, C.2, Scotland. A catalogue gives details the range of Anemostat draughtless aspirating air diffusers.

Projection microradiographic apparatus. Philips Electronics Inc., Instruments Division, 750 South Fulton Avenue, Mount Vernon, New York, U.S.A. A new folder on projection microradiography contains photographs and micrographs which illustrate a projection microradiographic apparatus for analyses of opaque specimens.

Diaphragm valve. Talbot Stead Tube Company Ltd., Green Lane, Walsall. Details are given of a three-way diaphragm valve which is claimed to be simple to operate and is fitted with a selector device that indicates which side of the valve is closed. The valve is leak proof and the mechanism is simple.

X-ray instruments. Philips Electronics Inc., Instruments Division, 750 South Fulton Avenue, Mount Vernon, New York, U.S.A. A 12-page booklet gives engineering data on new X-ray instruments for element analysis and structure determinations.

Transformers and coils. Atkins, Robertson and Whiteford Ltd., Industrial Estate, Thornliebank, Glasgow. An 8-page folder gives details of a range of transformers and coils.

Servo units. Harvey Electronics Ltd., Farnborough Road, Farnborough, Hampshire. Details have been made available of a new range of servo-units which are claimed to be more powerful, more compact and more accurate than previously marketed units.

Automatic control valves. Magnetic Valve Co. Ltd., 28 St. James's Place, London, S.W.1. The range of magnetic valves described in a new, illustrated catalogue covers equipment suitable for the control of non-corrosive liquids and gases flowing through pipes such as low, medium and high pressure hot water, saturated steam, Town's gas, oil, and compressed air. A hot water and steam pipe sizing rotary calculator is supplied with the catalogue.

Vacuum furnace. Wild-Barfield Electric Furnaces Ltd., Elecfurn Works, Otterspool Way, Watford-by-Pass, Watford, Hertfordshire. Leaflet VL 757 describes the model 2904 resistance heated vacuum furnace. The equipment is a self-contained unit suitable for operation up to 2000° C.

Electronic chassis assembley system. Shandon Electronics Ltd., 6 Cromwell Place, London, S.W.7. An illustrated brochure describes the Rapikon electronic chassis assembly system. Pre-punched holder plates take such focal components as valves and these plates are individually placed where required. Slotted plates and girders are mounted vertically on a rack to any required layout which can be easily modified.

Photoelectric counters. Radiovisor Parent Ltd., Stanhope Works, High Path, London, S.W.19. A 4-page illustrated leaflet gives details of a range of photoelectric counters, including the photoelectric counting unit type CU 56; high speed electronic counter type E.M.I., and the electronic pre-set batch counter type B.C.P.4.

Notes and comments

British Nuclear Energy Conference: lecture symposium on the Geneva conference.

To help scientists and engineers to assimilate the large amount of material (over 2000 papers) produced for the second International conference on the peaceful uses of atomic energy (Geneva, 1–13th September 1958), the British Nuclear Energy Conference (of which the Institute of Physics is a constituent body) has planned a one-day lecture symposium to take place on Thursday, 11 March, 1959.

For the purpose of the symposium, the Geneva conference papers will be classified into 6 or 7 groups, and leading experts in each field will attempt to highlight the most important aspects of the new information.

The lectures will be printed in the April 1959 issue of the *Journal of the British Nuclear Energy Conference* and further details will be announced in due course.

User-specification for sealed X-ray tubes for use in X-ray diffraction

The X-ray Analysis Group of the Institute of Physics announces that a panel of its Equipment Sub-Committee has completed the preparation of a user-specification dealing with the design of sealed X-ray tubes for use in X-ray diffraction and similar applications. Copies of this specification may be had by anyone interested on application to the Honorary Secretary of the Equipment Sub-Committee of the X-ray Analysis Group, Dr. E. G. Steward, Research Laboratories of The General Electric Co. Ltd., Wembley, Middlesex.

Proceedings of the Royal Institution

The Friday evening discourses given at the Royal Institution of Great Britain in the heart of London are well known to most of our readers as understandable yet authoritative accounts by specialists of recent advances in a wide field of learning. These discourses, concerned mainly with scientific subjects, are published in the *Proceedings* which have appeared annually. In future the *Proceedings* will appear three times a year at a charge of 8*s.* 6*d.* a part or 21*s.* p.a., commencing January next. The first of the new series contains the following discourses: Sir Lawrence Bragg on "Gemstones," Mr. John M. Allegro on "The Dead Sea Scrolls," Dr. L. Radzinowicz on "Changing attitudes towards crime and the devices used to combat it," Professor W. R. Hawthorne on "Aero-thermodynamics," Professor C. D. Darlington on "The control of evolution in man" and Professor R. J. Pumphrey on "Hearing in man and animals."

Orders for these *Proceedings* should be sent to the R
Institution, 21 Albemarle Street, London, W.1.

Control

The first issue of a new monthly periodical entitled *Con*
has recently appeared. Its aim is stated to be the cove
of "every aspect of control engineering for the engineer
scientist, and use of control equipment," including syste
instrumentation, data processing, engineering and appl
tions. The Editor is Mr. C. T. Rivington and he ha
distinguished panel of editorial consultants. This is
published in July, contains the following articles: "Electr
systems for industrial measurement and control"
M. V. Needham; "Dynamics of mechano-pneum
systems" by J. E. Samson; "What is control engineerin
by C. M. Burrell and J. K. Lubbock; "Computer contro
machine tools" by D. T. N. Williamson; "An element
survey of digital codes" by G. C. Tootill. A buyers' gu
and the usual regular features of this type of commer
periodical are also included.

Control is companion to the publisher's *Nuclear Po*
and is produced in the same attractive modern form
Once more it is our pleasure to wish success to anot
contemporary resulting largely from the application
physics in industry.

The magazine is produced by Rowse Muir Publica
Ltd., 3 Percy Street, London, W.1. The price is £2 2*s*
p.a. plus 10*s*. postage in the U.K., £3 3*s*. overseas, a
$8 in the U.S.A. and Canada.

British Journal of Applied Physics

Contents of the October issue

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BINDING ORDERS

Orders and enquiries about the binding of back-numbers of the *Journal of Scientific Instruments* and of the *British Jour*
of Applied Physics should now be sent direct to Messrs. E. A. Weeks and Son, 168 Gower Street, London, N.W.1 (EUSton 46
and *not* to The Institute of Physics. This new arrangement does not involve any change in price.

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ORIGINAL CONTRIBUTIONS

Soft X-ray spectroscopy using an electron multiplier

By J. A. CATTERALL, Ph.D., D.I.C., B.Sc., L. F. WILSON and J. TROTTER, National Physical Laboratory, Teddington, Middlesex

[*Paper received* 7 *May*, 1958]

The modification to a soft X-ray spectrograph in order to use an electron multiplier instead of a photographic plate is described. The instrument has been calibrated with the aluminium and magnesium L_{23} spectra.

INTRODUCTION

e method of soft X-ray spectroscopy as a means of estigating the electron energy distribution of the valence nds of solids is well known, and reviews of the subject ve been given by Skinner(1) and Tomboulian.(2) The velengths of the X-rays used in this type of work usually in the range 50–600 Å, and they are excited by bombarding specimen with electrons of one or two kilovolt energies. account of the instrument in use at the National Physical boratory has been given by Gale and Trotter,(3) and the rpose of this paper is to describe the improvements made the spectrograph in order to record the spectra with an ctron multiplier instead of with a photographic plate. e electrodes of the multiplier are of a copper–beryllium oy, and this type of unit was first used in soft X-ray ectroscopy by Piore and others.(4) In the present case, wever, both the method of moving the multiplier and of easuring its position are different. The instrument has been cused and calibrated with the first and second orders of e magnesium and aluminium L_{23} spectra.

EXPERIMENTAL DETAILS

The sensitivity of the multiplier is much greater than that the photographic plate, so that a record of the emission ectrum may be obtained in a much shorter time with a wer power input to the target. The surface of the specimen consequently much less liable to be contaminated during e course of the experiment.

The general arrangement of the spectrograph and its xiliary equipment is shown in Fig. 1. The cylindrical cuum tank has been drawn back on its runners, exposing e track of the Rowland circle. The spherical glass target amber is attached to the far side of the instrument. The utput pulses from the multiplier are amplified and counted n the standard circuits visible in the background. A closer ew of the arrangement inside the vacuum tank may be btained from Fig. 2. The stainless steel carriage which pports the electron multiplier is driven around the Rowland rcle by a rack and pinion, and the rack and pinion is itself perated by a worm and wheel. The shaft to which the orm is attached is rotated from outside the tank by means f a handwheel on a separate shaft passing through a vacuum al. A single-point dog-clutch connects the worm-shaft to e handwheel shaft when the vacuum tank is in position. stainless steel scale is fixed to the curved outside edge of e carriage and is engraved in intervals of 0·05 in. The ale is viewed from outside the tank by a microscope which bdivides each interval into fifty parts. The scale can erefore be read to 0·001 in., which corresponds to 0·05 Å the region 200–300 Å. The scale travels past a fine wire, rigidly fixed in a steel mounting attached to the base of the spectrograph, which provides a fiducial mark. This method of measuring the position of the multiplier carriage is possible because the copper–beryllium electrodes are insensitive to radiation of wavelength greater than 3000 Å, which allows an optically-flat glass window to be inserted into the side of the tank through which the carriage and scale may be seen. It has the great advantage over the calibrated screw used in earlier work(4) in that the adjustment of the carriage and the measurement of its position are independent of any backlash in the driving mechanism.

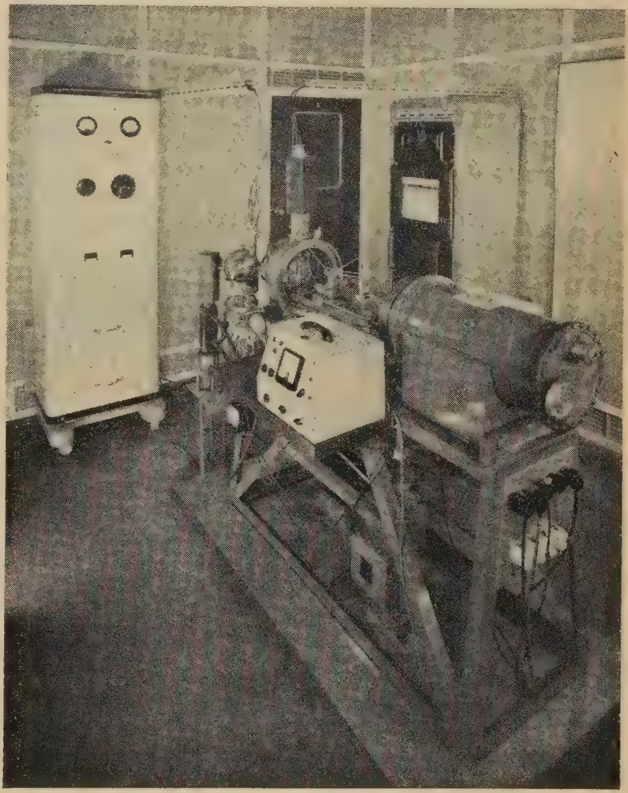

Fig. 1. General arrangement of spectrograph and auxiliary equipment

The entrance slit to the multiplier is mounted in a brass housing screwed on to the carriage. The width of the slit and its position along the diameter of the Rowland circle are adjustable independently. The framework which supports both the potential divider and the electrodes is fixed to the slit housing, although the electrodes have been removed in

Fig. 2 to show the position of the slit. The leads taking the high voltage and carrying the output pulses pass from the divider through glass-to-metal seals in the wall of the spectrograph. Ideally as the multiplier moves round the Rowland circle it should be rotated so that the plane of the slit system remains normal to the diffracted X-ray bea This would involve considerable complications, so that mean position of the multiplier in the working range of t instrument was adopted. It is inclined at about 15° to t diameter of the Rowland circle. The width of the multipli slit is a compromise between a high resolution and a hi counting rate, and a convenient value was found to 0·1 mm. This width enables the L_2 emission band aluminium to be distinguished from the L_3, a difference about 1 Å. The resolution possible is governed by t multiplier slit-width since the decrease in resolution arisi from the fact that the full width of the grating is being us instead of the optimum width is negligible by compariso With a slit-width of 0·1 mm a resolution of about 0·8 Å possible. This figure was arrived at using two lines of equ intensity having Gaussian profiles with widths at ha maximum of 0·04 eV, this width being calculated from t source slit-width and the grating constants. The resoluti criterion adopted was a decrease of 2% in the over intensity midway between the lines, since this is the limit the counting accuracy. It is possible to improve the resoluti of the instrument considerably by using a narrower multipli slit and a multiplier with a greater number of stages, but th is not necessary for the present purpose.

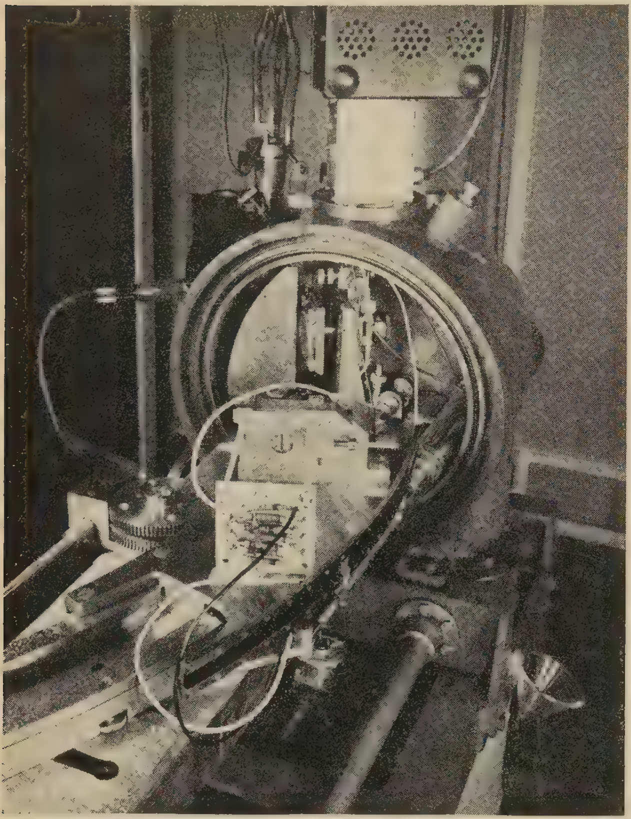

Fig. 2. View inside vacuum tank

Fig. 3 shows the vacuum tank in its working position, an also the microscope which is fixed to the outer wall of the tan

ACCURACY OF COUNTING

The details of the target chamber and the preparation either evaporated or rolled specimens have been describe by Gale and Trotter.$^{(3)}$ The power supply to the target mu be stable when recording spectra with the multiplier althoug this is not necessary with photographic plates. The power continuously controlled by hand during the course of th experiments, which usually last for some minutes. Tes were made to determine the change in counting rate with th change in the target power. The instrument is normal operated at 500–1000 V with 5–10 mA emission current, an at these values a change of 1% in the pow supply produces a change in the counting ra of the same order of magnitude. The powe is controlled well within these limits sinc changes in the power supply arise either throug mains voltage fluctuations, changes in th emission properties of the filament, or change in the vacuum, and these alter only slowly.

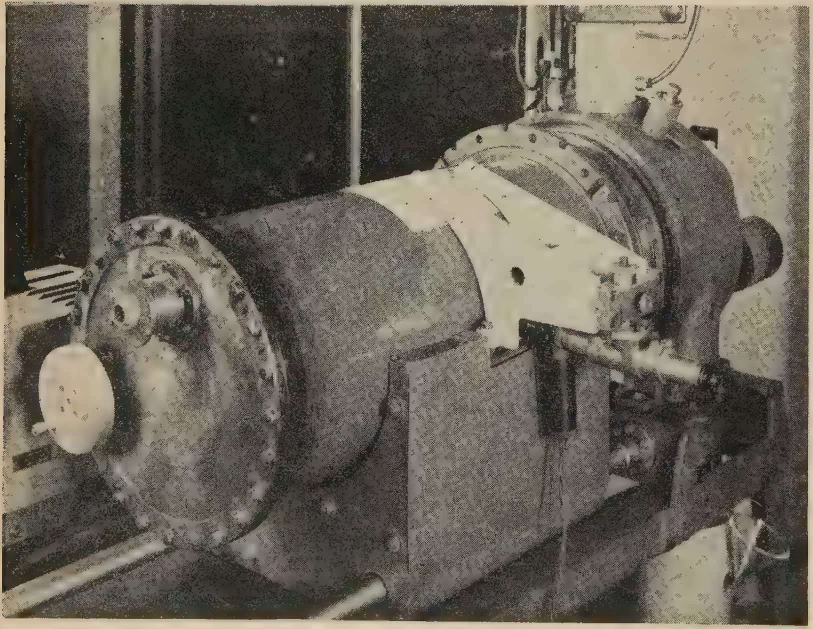

Fig. 3. Vacuum tank in working position showing microscope on outer wall

The effect of the degree of vacuum in th tank on the multiplier and the counting rat was also investigated. A change of 2% in th rate is caused by a fall in the vacuum fron 6×10^{-6} to 7×10^{-6} mm of mercury, a though in practice the change occurring durin an experiment is negligible. A further variab is the voltage across the potential divider of th multiplier, and the e.h.t. unit supplying th voltage is stabilized to 0·1%. Fluctuations i the rate with this value of the stability ar ±0·5%.

There is always present an error due to th statistical nature of the counting process. In given interval of time the relation between th number of counts occurring to the true averag number is governed by Poisson's Law. With count of 30 000/min on a background o 2000/min, the probability is 0·95 that the erro ithin ±1·1%. A series of tests showed that in practice the rall accuracy which may be expected from the counting cess during any one experiment is ±2%.

L EMISSION BANDS OF ALUMINIUM AND MAGNESIUM

n obtaining an emission band counts of one minute ation were taken at various parts of the spectrum. ially a rough survey of the general shape of the band was ained with counts at ten or fifteen positions. The next p, using a fresh target specimen, was an examination of a ited portion of the band with about five counts at closely ced intervals of the spectrum. In this way no target was d which had been subjected to bombardment for longer n five to six minutes. The various sections of the band btained by this method were then assembled to give the verall picture.

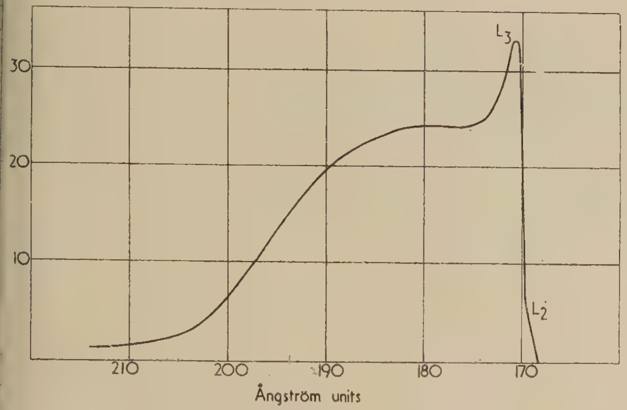

Fig. 4. Aluminium L_{23} emission band

The spectrograph was focused and calibrated with the nission bands of aluminium and magnesium. The curves nown in Figs. 4 and 5 were obtained from about eight xperiments on each element. For the purpose of calibra- on the values of the emission edges tabulated in Ref. (2) ere used. This gives the aluminium L_3 edge at 170·56 Å and the magnesium L_3 edge at 250·45 Å. The shapes and widths of the bands when matched at the peak intensities agree well with previous work using the photographic method, on both aluminium$^{(1, 5)}$ and magnesium.$^{(1, 3, 5)}$

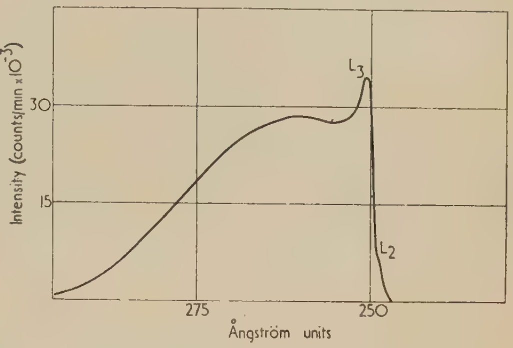

Fig. 5. Magnesium L_{23} emission band

ACKNOWLEDGEMENTS

The work described above has been carried out as part of the General Research Programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

The modifications to the spectrograph were carried out by Mr. J. R. White and Mr. G. Long of the Metrology Division, National Physical Laboratory.

REFERENCES

(1) SKINNER, H. W. B. *Phil. Trans Roy. Soc.*, *A*, **239**, p. 95 (1946).

(2) TOMBOULIAN, D. H. *Handbuch der Physik*, **30**, p. 246 (1957).

(3) GALE, B., and TROTTER, J. *Phil. Mag.*, **1**, Series 8, p. 759 (1956).

(4) PIORE, E. R., HARVEY, G. G., GYORGY, E. M., and KINGSTON, R. H. *Rev. Sci. Instrum.*, **23**, p. 8 (1952).

(5) CADY, W. M., and TOMBOULIAN, D. H. *Phys. Rev.*, **59**, p. 381 (1941).

A method of maintaining temperature control over a wide range

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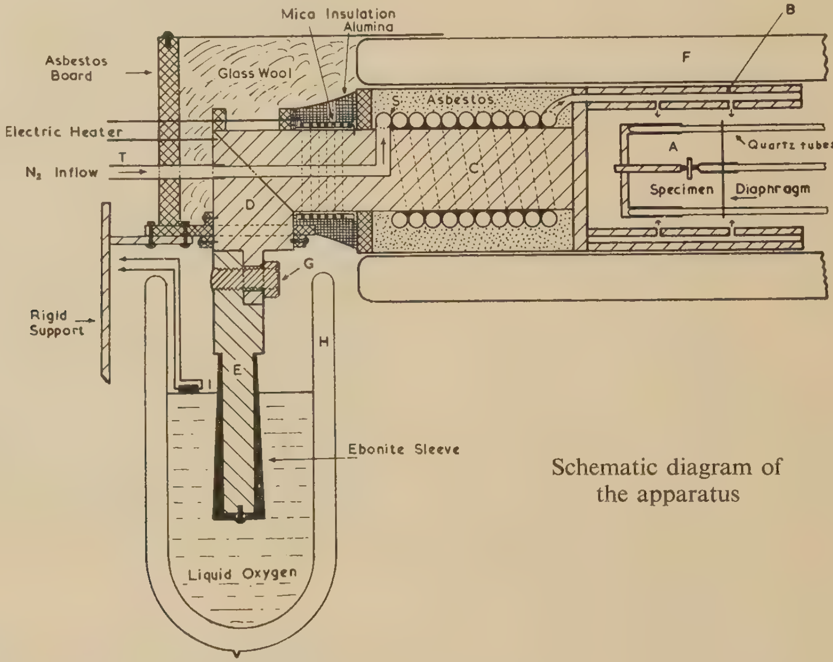
It is sometimes desirable to control the temperature in an apparatus without having to use a bath of stirred liquid as a means of maintaining thermal equilibrium. The apparatus described is applicable to such cases, thermal equilibrium being maintained by a stream of gas that is brought to the required temperature in a heat exchanger. The system is effective in the range −150 to 200° C, and the temperature stability varies from about ±1° C in the range 20 to 200° C to ±5° C below −110° C.

The apparatus described was designed to control the temperature of small ferroelectric specimens during an investigation of their electromechanical properties. In this investigation a dynamic strain gauge,$^{(1)}$ sensitive to displacements as small as 10^{-7} cm was used, and in order to utilize the full sensitivity of the gauge great care was necessary to prevent it from being actuated by extraneous vibrations. The shock-absorbers used have been described elsewhere,$^{(1)}$ but it is of equal importance that the temperature-controlling system should not itself introduce significant vibration. To avoid the vibrations inherent in any system incorporating a bath of stirred liquid a stream of gas was used to maintain thermal equilibrium. The use of a gas in place of a liquid has the added advantage that the same medium can be used throughout a very wide temperature range. On the other hand, the method is wasteful of gas, partly because of the relatively low thermal capacity of gases, and partly because the gas cannot conveniently be re-used. Furthermore, much thermal energy escapes with the emergent gas.

A schematic diagram of the apparatus is shown in the figure. The specimen is contained within the enclosure *A*, bounded by the double-walled copper vessel *B*, of external diameter 6 cm. To permit access to the strain gauge, vessel *B* is open at one end, and connexion between the specimen and the main body of the strain gauge is made by a system of quartz tubes. The vessel *B* is in thermal equilibrium with the massive copper bars *C* and *D*, and the temperature of this mass of copper may be varied at will. A slow stream of gas emerging from a number of holes in the interior of *B* ensures that the temperature of the specimen is equal to that of *B*. A hole is drilled down the axis of *C* to a depth of about 10 cm, and to the open end is joined the German silver tube *T* which comprises the gas inlet. About 3 m of copper tubing, one end of which is let into *C* to join the far end of the drilled hole at *S*, is closely wound round the exterior of *C*, and finally enters the hollow space between the walls of *B*.



Schematic diagram of the apparatus

Around *C* is also wound an electric heater consisting of about a metre of 18 s.w.g. Vachrome wire. Power is provided by a 14 V, 12 A transformer, the primary of which is connected to a stabilized mains voltage power supply through a Variac transformer. When in use the latter provides a sensitive temperature control, and the maximum temperature of 200° C is reached when the Variac output is set at about 200 V. All the joints in the apparatus are silver soldered (melting point 650° C), so that temperatures considerably in excess of 200° C could be reached by using greater power inputs.

When it is required to cool the apparatus below room temperature the copper bar *E* (diameter 2 cm and length 10 cm) is joined to *D*. The adjoining faces are machined to fit one another closely, and they are held tightly together by the bolt *G*. To ensure good thermal contact the two faces are tinned and the joint is sweated together as the b is tightened. (The purpose of the joint is that *E* may removed to reduce heat losses when the apparatus is operat at high temperatures.) The bar *E* is sheathed in a taper ebonite sleeve having a wall thickness of about 1 mm at t upper end, and of about 3 mm at the lower end. Liqu oxygen is introduced into the Dewar flask *H*, and as t level of the oxygen in the flask is raised the area of the ebon in contact with the oxygen increases, and simultaneously t average thickness of the operative section of the ebon sleeve decreases. Both these factors tend to reduce t temperature difference between the copper bar and t oxygen, and thus the amount of heat drawn from the bar controlled by raising or lowering the level of liquid oxygen the flask.

In practice this method of control is ineffective below temperature of about −110° C, the reason being that there after it would be necessary to use a prohibitively large are of ebonite sleeving to obtain sufficient cooling. Howeve when only the extreme end of the part of *E* not covered wit ebonite is immersed, the temperature is stable at about −11 C, whereas if the whole of *E* is immersed the temperatur falls to about −150° C. This indicates that there is an appre ciable temperature gradient in the exposed part of *E*, and i fact a moderately reliable control within the range −110 t −150°C is obtained by varying the oxygen level above th top of the ebonite. In the range 20 to −30° C the mos satisfactory method of control is to immerse the bottom 2 c of *E* in the liquid oxygen, and to vary the temperature b using the electric heater at small power inputs.

The level of the liquid oxygen in the flask is automaticall maintained at any desired level by a device in which a carbo resistor *I* is used as a temperature sensitive element. B making *I* one arm of a potential divider the voltage dro across it is made to change by about 30% whenever *I* i immersed in the liquid oxygen. This variable voltage i used to control the action of a thyratron circuit, essentiall similar to that previously described by Fred and Rauh,(2 and thus to control the transfer of oxygen into the flask. Th tion of *I* relative to *E* is readily adjusted, and it is set at evel the liquid oxygen is required to reach. It is possible aintain the oxygen level constant to ±1 mm.

ecause of its relatively inert properties nitrogen gas is l, the nitrogen being derived from cylinders of the comsed gas. These cylinders normally contain small amounts ater vapour which, if not removed, freezes in the tubing obstructs the gas flow. The gas is therefore dried before ters the apparatus by passing it through a cylinder coning silica-gel. The rate of flow must be such that the rgent gas can always attain the temperature of *B*, and a of flow of 12 ft^3/h feet per hour is found to be suitable. he (spring) diaphragm and quartz tubes form part of the in gauge,(1) the main part of which remains at room perature and is not shown in the diagram, being at the t-hand end of the quartz tubes. Hence the Dewar flask hich provides the thermal insulation is made open at h ends, and has a length of 34 cm. In order to allow for thermal expansion when the inner and outer surfaces are idely different temperatures, it was found necessary to e the inner surface deeply corrugated in the manner of al bellows. For clarity these corrugations are omitted n the diagram. The region of the joint between the s *C* and *D* is insulated as effectively as possible with glass ol. The emergent gas stream is directed along the inner face of the flask and thence over the glass wool, and this ps to reduce heat losses.

A constant rate of flow of gas is maintained with a regulator valve, and consequently the temperature stability depends, apart from small variations in the heat losses, only on the constancy of the power input and of the liquid oxygen level in the high- and low-temperature cases respectively. Above 20° C a temperature stability of ±1° C over an hour is easily maintained, while below that temperature and down to −110° C a stability of ±2° C is usual. However, the former figure can also be attained in the range 20 to −110° C if the liquid oxygen level controller is set at maximum sensitivity, but since a considerable amount of liquid oxygen is wasted at each transference, the sensitivity is normally set at a lower value. Below −110° C the stability is seldom better than ±5° C. When the temperature is changed by 20° C about an hour must elapse before the temperature is again stable.

ACKNOWLEDGEMENTS

One of us (H. L. A.) is indebted to the C.S.I.R. of South Africa for financial assistance.

REFERENCES

(1) Gibbs, D. F., and Allsopp, H. L. *J. Sci. Instrum.*, **34**, pp. 308–311 (1957).

(2) Fred, M. S., and Rauh, E. G. *Rev. Sci. Instrum.*, **21**, p. 258 (1950).

A cryostat for reactor irradiations in liquid nitrogen

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A liquid nitrogen cryostat which has operated inside the BEPO reactor at Harwell is described. Provision was made for removing irradiated specimens in liquid nitrogen after periods of up to one month. Some difficulties encountered and the methods used to overcome them are discussed.

GENERAL DESIGN

ring a recent study of irradiation damage in solids(1, 2) it s found necessary to carry out reactor irradiations at the uid nitrogen boiling point (−196° C). The apparatus to described was designed to maintain a small bath of liquid rogen in the centre of the BEPO reactor at Harwell periods of up to one month. As it is difficult to make curate measurements of physical quantities in the reactor, ovision was made for removing irradiated specimens to the oratory without allowing their temperature to rise.

The working principles of the cryostat are illustrated in g. 1. Liquid was drawn from a reservoir outside the actor into the cryostat by a partial vacuum produced by suction pump. Control was achieved with the aid of thermocouple whose temperature rose when the liquid rogen level fell below it. The e.m.f. from this thermouple was fed to a control unit which switched the pump and off as required.

The cryostat was installed in a vertical experimental hole the reactor and the lower part was fitted inside a wateroled uranium cylinder which increased the fast neutron x. The overall length of the cryostat was 24 ft: its aximum diameter 2 in. With the exception of the thermocouple wires and the specimens all parts of the cryostat within the reactor were made of aluminium with arc welded joints. The constructional details of cryostat, transfer tube and reservoir are shown in Fig. 2.

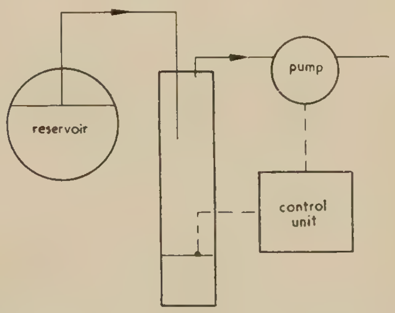

Fig. 1. Block diagram of cryostat system

THERMAL INSULATION

In the BEPO reactor at ∼10^{12} neutron/cm^{-2} s^{-1} the heating due to β- and γ-ray absorption amounts to about 10 mW/g in aluminium. It is therefore pointless to instal thermal insulation which reduces the heat leakage far below this figure. The cryostat was insulated by a vacuum jacket (17, Fig. 2) pumped to 10^{-2} mm; no improvement in liquid nitrogen consumption was observed if the pressure were reduced further. For the insulation of the transfer tube (8) which was not exposed to high levels of radiation, it was considered advantageous to improve on the vacuum insulation. The tube was therefore surrounded by a jacket filled with Sil-o-cel diatomaceous powder (by Johns-Manville Co. Ltd.) and connected to the same vacuum pump as the cryostat jacket. The thermal insulation of Sil-o-cel at 10^{-2} mm is equivalent to that of an evacuated space at 10^{-4} mm. To reduce the radiation hazards the vacuum lines to the cryostat jacket (10*b*) were led through the reactor shield in a helix. Two vacuum valves were fitted, one to the lines from the cryostat jacket and one to that from the transfer tube jacket (10*a*), so that each might be isolated independently when the apparatus was dismantled to remove specimens. During operation a two-stage rotary vacuum pump was permanen connected to the system.

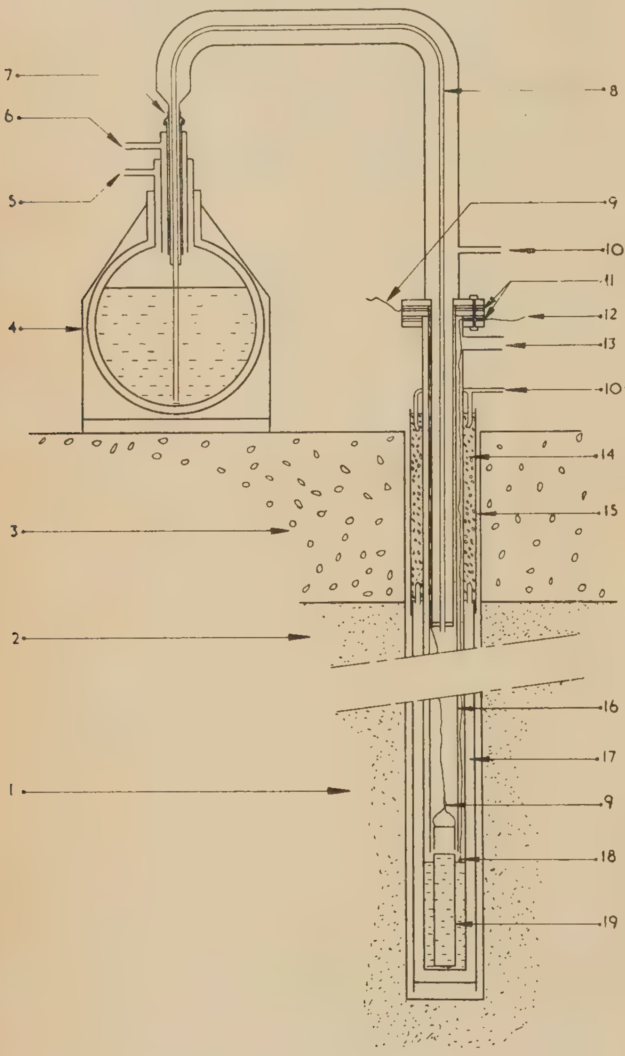

Fig. 2. Vertical section through cryostat

(1) Reactor core, (2) reflector, (3) shield, (4) reservoir, (5) vent, (6) filling tube, (7) rubber seal, (8) transfer tube, (9) lifting wire, (10*a*) vacuum line to transfer jacket, (10*b*) vacuum line to cryostat jacket, (11) two pairs of rubber washers, (12) thermocouple wires, (13) suction line, (14) polythene and lead shot, (15) nickel-plated steel tube, (16) inlet tube, (17) vacuum jacket, (18) thermocouple junction, (19) specimen can.

RADIATION SHIELDING

The cryostat vacuum jacket extended only as far as t inside of the reactor shield which is 7 ft thick. From t point upwards its place was taken by polythene loaded w lead shot (14) encased in a nickel-plated steel tube (1 This shielding material was made by pouring a mixture polythene powder and lead shot into position, a tubu heater was then passed over the steel tube to fuse t polythene.

The remaining channels for radiation were the $\frac{3}{16}$ diameter transfer tube and a narrow annulus $\frac{3}{32} \times 1$ diameter through which the nitrogen gas was exhausted the suction line. With the reactor running at full power beam containing 5 tolerances of fast neutrons and 5 toleran of γ-rays was observed directly above the cryostat. further shielding was considered necessary.

THE NITROGEN CIRCUIT

The liquid nitrogen reservoir (4) was a 15-gallon stora vessel of standard A.E.R.E. design modified to permit filli whilst the transfer tube was in position. Filling was carri out by connecting a 5-gallon vessel of liquid nitrogen to t filling tube (6) and forcing the liquid into the reservoir wi 5 lb/in.^{2} of nitrogen gas.

During operation the liquid was drawn through t transfer tube into the cryostat where it fell 17 ft down t inlet tube (16), into the specimen can (19). Having fil this up to its overflow holes (see Fig. 3) the liquid filled t surrounding space to the level of the thermocouple juncti (18). Cold gas boiling off from the liquid passed up t outside of the inlet tube (16) to the suction line (13) outsi the reactor. Cooling the inlet tube in this way was four to effect a considerable economy in liquid nitrogen.

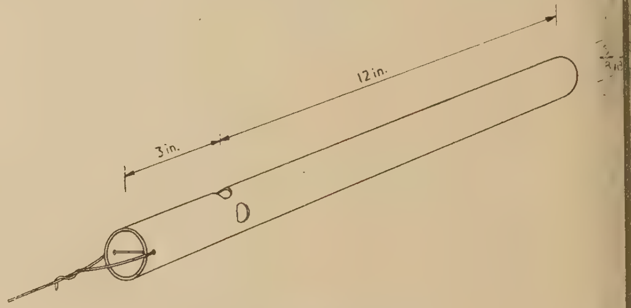

Fig. 3. Specimen can

The suction pump was of the type used in milki machines, having a speed of 8 ft^3/min at 650 mm pressu Such a high pumping speed was necessary to overcome t back pressure built up in the transfer tube and cryostat duri the first stages of nitrogen delivery. As the exhaust gas fro the pump contained small amounts of radioactive dust it w fed into the reactor coolant air duct. When the pump w shut off a relief valve provided an outlet for the gas boili off from the cryostat. This consisted of a polythene fla covering a hole in the suction line and gas issuing from it w also fed to the reactor coolant air duct.

THE CONTROL SYSTEM

The glass insulated iron-constantan thermocouple w connected to a recording potentiometer (by George Ke

). Two cam wheels, attached to the drum carrying the ntiometer slide wire, were made to operate microswitches nected to the starter switch of the suction pump motor. as arranged that when the thermocouple rose above 5° C the pump was switched on and when the temperature below −190° C it was switched off again. Under these litions the pump was on for about 20 s at intervals of n when the reactor was at full power. It was proved during cycles of this sort the liquid nitrogen always l the specimen can up to the overflow holes although the l in the surrounding space necessarily fluctuated.

third cam wheel on the potentiometer drum was made operate a microswitch which rang an alarm bell if the perature rose above −150° C. A thermal delay switch connected in parallel with the suction pump motor to nd an alarm if the pump ran for more than 2 min tinuously. This device provided adequate warning of liquid nitrogen supply running out or of a fault in the troller. Circuits were also arranged to give warning in event of mains failure; an electro-magnetic valve then ated the vacuum system from the pump.

OPERATION AND PROBLEMS ENCOUNTERED

During operation with the reactor at full power the liquid rogen consumption was between five and seven gallons day. The reservoir was filled up daily and maintenance the control equipment was carried out during the weekly it down of the reactor. The loading and unloading of cimens was also carried out during shut-down with the nsfer tube removed. Before extracting irradiated specins the cryostat was flooded with liquid nitrogen. During nsfer from the cryostat to a lead shielded vacuum flask liquid nitrogen, sufficient liquid was retained in the cimen can to keep the specimens cool.

The liquid nitrogen supplied by the British Oxygen Co. d. contained about 1% of oxygen. Under irradiation, ides of nitrogen were formed as a sludge in the bottom of cryostat which caused trouble for two reasons. Firstly, if the cryostat was in operation for more than a month the accumulation of sludge made it difficult to withdraw the specimen can; secondly, on warming up the cryostat the nitrogen oxides present attacked the aluminium vacuum jacket. This was alleviated by purging the cryostat with dry nitrogen or by starting the cryostat again immediately after warming up.

In addition to chemical action inside the cryostat, water condensing on the outside caused corrosion under irradiation. In the prototype, which had a sand-filled shielding plug, serious corrosion occurred on the vacuum lines where they left the vacuum jacket. This point was therefore protected by the use of polythene and lead shot as a shielding material which also formed a barrier to condensation. The steel tube (15) enclosing the shielding material was also nickel-plated.

It has been reported that explosions due to liquid ozone have occurred in cryostats operating under irradiation.(3, 4) Cryostats of the above type have been in operation at Harwell since March 1955 and no explosions have been observed. However, the gas boiling off from the cryostat after a month's operation was analysed by mass spectrometry and shown to contain the following volume percentages of gas: nitrogen, 87%; oxygen, 12%; argon, 0·6%; nitrous oxide, 0·1%. No other gas was detected in concentrations greater than 0·01%. Tests with benzidene paper confirmed the presence of oxides of nitrogen and the absence of ozone. It is considered that provided the liquid consumption is small and the oxygen concentration is always low, oxides of nitrogen are formed rather than ozone.

REFERENCES

(1) Kinchin, G. H., and Thompson, M. W. *J. Nuclear Energy*, **6**, p. 275 (1958).

(2) Thompson, M. W. *Phil. Mag.* (8) **3**, 28, p. 421 (1958).

(3) Klontz, E. E. United States Atomic Energy Commission unclassified report number 2267 (U.S.A.: Pardue University, 1952).

(4) Coltman, R. R., Blewitt, T. H., and Noggle, T. S. *Rev. Sci. Instrum.*, **28**, p. 375 (1957).

A variable radio-frequency inductance for the Birmingham proton synchrotron

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[*Paper received* 10 *March*, 1958]

An inductance capable of varying from 26 to 0·033 μH is described. The variation is achieved by saturating a ferroxcube core in a coaxial cavity by means of a large biasing current passing down the centre of the inner conductor of the cavity.

The inductance is used to tune the Cee of the Birmingham proton synchrotron over the frequency range 0·3–9·6 Mc/s. It is operated at a power level up to 40 kVA. The method and circuits by which the bias current is controlled to give the desired inductance at any frequency are also explained.

he design of the acceleration electrode or Cee for the irmingham proton synchrotron has led to a difficult compromise between radio-frequency power and radio-frequency ıning. The Cee(1) which subtends 102° of arc round the ynchrotron may be regarded as a low-impedance transmission line fed in the centre, and has a lumped capacity at low frequencies of 5900 pF rising, because of wavelength effects, to 9300 pF at 9·6 Mc/s, the highest acceleration frequency. The impedance presented to the amplifier is, therefore, capacitive and varies from − 90 JΩ at the initial frequency of 0·3 Mc/s to − 1·8 JΩ at the highest frequency. Thus to provide a Cee end voltage of 300 V r.m.s. would require both an amplifier capable of handling 40 kVA at

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* Now at the High Voltage Engineering Corp., Massachusetts, J.S.A.

9·6 Mc/s, and at the same time one which was sufficiently broad-banded to give the required output at the low frequencies. Rather than build such a large amplifier and its bulky power supplies, it was decided to raise the impedance of the Cee by tuning it with a parallel inductance which could be varied in a controlled manner.

The tuning requirement is much more stringent than is usually encountered in proton synchrotrons, both because of the large frequency range 32 : 1, a direct result of the low injection energy, and the high capacity of the Cee arising from the lack of the usual straight sections such as appear in the race-track synchrotron. The range of inductance needed to achieve perfect tuning of the Cee is 47 to 0·033 μH, or a ratio of 1420 : 1. Fortunately, more detailed considerations show that a range of 800 : 1 is quite adequate. Until recently the radio-frequency system has been operated with fair success by tuning the Cee with what is called the "mercury inductance." This consists of a coil wound on a former which is dipped into a pool of mercury at a controlled rate during the acceleration cycle. The coil is wound from copper wire which has been chromium-plated to make it resistant to attack by mercury. It was not found possible to wind the coil in a continuous spiral, and, in order to obtain a high enough inductance at low frequencies, part of it was made of "pancakes" of winding joined on the surface of the former. These steps in the inductance produced transients in the accelerating voltage and the resultant phase oscillations often caused the beam to be lost to the walls of the vacuum box. Perhaps the worst feature of this loss was that it made the beam intensity erratic from pulse to pulse.

Rather than continue to develop this mercury inductance, it was decided to investigate the possibility of building a saturable reactor to replace it in the hope of improving the stability of performance of the synchrotron.

DISCUSSION OF THE SATURABLE REACTOR

It is a well-known property of magnetic materials that the incremental permeability is a function of an applied d.c. field. A variable inductance can be constructed by taking advantage of this phenomena, and such an inductance is generally known as a saturable reactance. Comparatively little attention has been paid to this type of variable inductance at radio-frequencies because of the small range associated with it and the difficulty of providing an uncoupled biasing field.

The inductance of a winding consisting of N turns on a toroidal core of permeability μ is given by

$$L = 4\pi N^2 A\mu/10^9 \mathscr{L} \qquad (1)$$

where A = the cross-section of the core in square centimetres; $\mathscr{L}$ = mean path length of the flux in centimetres; and μ = permeability of specimen. The permeability of free space $\mu_0 = 1$.

This expression shows that L is proportional to μ if the leakage inductance can be neglected. Experimentally this is found to be true while the reluctance of the core is small compared with its surroundings, but as the permeability falls the flux distribution commences to change. A direct result of this change is that the effective path length $\mathscr{L}$ becomes smaller and the range of inductance predicted by equation (1) is not obtained.

The large range of inductance required to meet Cee tuning requirements meant that a geometry had to be found which would permit full advantage to be taken of the possible change in permeability. If a single-turn inductance is extended the form of a coaxial cavity it makes an inductance of t type sought (see Fig. 1). Employing a uniform core mater the field configuration inside the cavity is independent permeability μ and, therefore, the inductance is given exac by equation (1). This geometry, too, is ideal for high f quencies as the leakage flux is very small, a fact which insu that the range of inductance obtained by varying μ is optimum.

By joining two such cavities in parallel as shown in Fig. an inductance is obtained which can readily be biased. important advantage of this form of geometry now becom apparent. There is no radio-frequency coupling betwe the bias winding passing through the centre of the coaxi line and the field in the cavity. At 0·25 Mc/s, the sk depth in brass is 0·02 cm, and it is easy to provide cav walls considerably thicker than this to prevent the electr magnetic field penetrating to the outside.

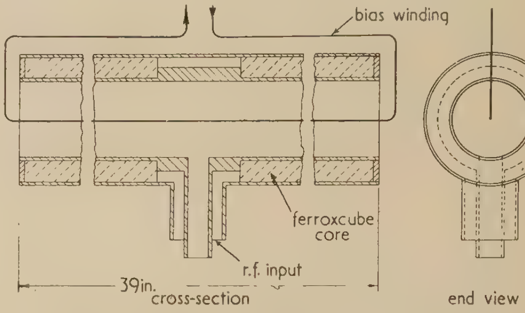

Fig. 1. Schematic diagram of inductance

Penetration of the cavity wall by the field of the biasi winding must, of course, occur. Fortunately, control usually desired at considerably lower frequencies than th signal frequency, and a wall thickness can be found that w permit control but prohibit leakage of the radio-frequenc field. In the inductance discussed here, the response of th core to transient variations in the bias field is more meaningf than the penetration depth. Here the constant of importanc is L/R, L being the inductance of the cavity, and R th resistance of the single turn comprising the inner and out conductor and end plates. The time for a field to change b a given amount also depends on the amplitude of the drivin force. For example, in the inductance described below which for mechanical reasons was constructed from $\frac{1}{8}$ in wall brass tubing, R/L ranges between 10^{-1}–10^{-4} s, dependin on the degree of saturation of the core. This response prove to be quite adequate and obviously an order of magnitud could be won quite easily, if need be, by using thinner walle tubes. A very fast time response could be obtained b splitting the core across the centre plane perpendicular t the coaxial cylinders and insulating the halves from eac other. Precautions would have to be taken to ensure that n signal voltage developed between the different halves of th inductance.

CHOICE AND PROPERTIES OF CORE MATERIAL

Two materials immediately suggest themselves, a suitabl grade of ferroxcube or a core made up from "pancakes" o very thin Mumetal tape. It was decided to concentrate o finding a suitable grade of ferroxcube because of the eas with which the material can be handled and formed into able core. It is worth pointing out, however, that from point of view of electrical properties in this frequency ge, a core made from 0·0005 in. Mumetal tape would be erior to one of the same size formed from a grade "A" oxcube. The incremental permeability at 0·3 Mc/s ld be higher and the loss factor at frequencies up to Mc/s would be less than that of the ferroxcube.

arlier tests showed, as proved later to be the case, that a composed of FX/1076/A3 ferroxcube rings could be le into an inductance with the desired properties. Before ceeding to build a full-sized model, tests were made to ermine what range of permeability and hence inductance ld be achieved using reasonable bias currents. To do , a smaller version of the inductance was built from lve ferroxcube rings of the size shown in the inset to . 2. This figure shows the variation of permeability with

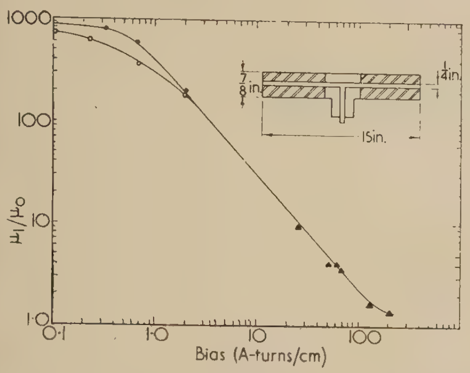

Fig. 2. Variation of permeability with saturating field

nset. Dimensions of ferroxcube rings used in the small version of the inductance

● = measurements made at 0·8 Mc/s.
○ = measurements made at 1·0 Mc/s.
▲ = measurements made at 9·5 Mc/s.

sing field for the fixed frequency, Tests showed, as has en reported earlier,[(2)] that at biasing currents greater than e or two ampere turns per centimetre the permeability is most independent of frequency. The minimum permeability ched in the tests was the same over a wide range of quencies.

The measurements were made using a General Radio idge and a variable frequency oscillator. Because the ometry of the conductor and ferrite core the measured luctance gives a true measure of the permeability to the ghest saturating fields. By using this technique it was ssible to extend the measurements of J. P. Blewitt and hers,[(2)] down to ratios of μ/μ_0 as low as 1·3.

The permeability was determined from the ratio:

$$\mu/\mu_0 = (L_\mu - L_s)/(L_0 - L_s) \qquad (2)$$

here L_μ = measured inductance of the coaxial cavity with rroxcube core; L_0 = measured air cored inductance; and = stray inductance of the leads, etc., and generally less an 0·005 μH.

Making use of the same experimental arrangement, the -factor of the ferroxcube core was measured over a wide nge of frequencies and bias currents. The curves shown in ig. 3 were obtained. All these readings were made at a w flux level. Before proceeding to build a full-sized ductance, measurements were made of the Q-value of the ductance at the expected operational flux levels for different saturating fields and frequencies. A 10–15% decrease in Q was observed at low saturating fields at high operating flux levels.

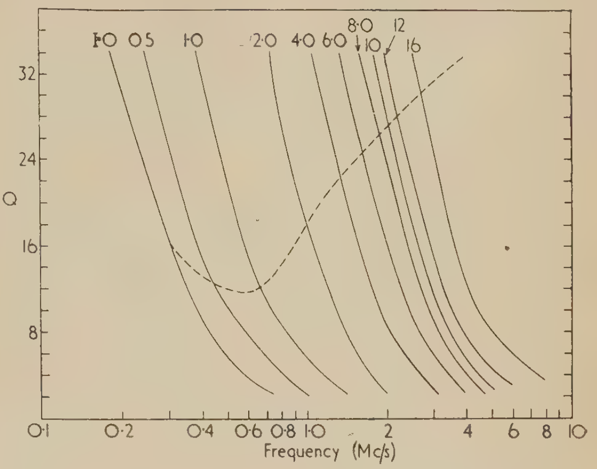

Fig. 3. Variation of Q with saturating field and frequency

I, bias current (A-turns/cm).
– – – – = locus of operation.

From this information and from the design information discussed below, an inductance of the dimensions shown in Fig. 1 was constructed. The properties of this core were found to agree closely with the model tests just discussed.

DETAILED DESIGN FIGURES

The resonant circuit comprising the Cee and the tuning inductance cannot be considered alone except to a poor approximation. The output impedance of the amplifier must also be taken into account. The inductance required to tune the output circuit was determined by combining measurements of the Cee impedance and of the output impedance of the amplifier. At low frequencies this impedance is essentially resistive because of the effect of the shunt impedance of the output transformer. The table makes the situation clearer. At a frequency of 0·3 Mc/s, the Q of the system is so low that there is little advantage to be gained by bringing it into resonance. All that need be done is to keep the impedance of the circuit above 20 Ω, which is the impedance into which the amplifier was designed to deliver its maximum power. This ensures that the desired voltage will be maintained across the Cee gaps, and the maximum value for the inductance was chosen on this basis. From experience with the coil inductance mentioned above, a low-frequency inductance of 26 μH was selected.

Circuit parameters versus frequency

Frequency (Mc/s)	*Combined impedance (Ω)*	*Inductance to tune system (μH)*	*Bias current (A turns/cm)*	*Measured Q of system*
0·3	53 –J 5·5	47·0*	0	—
0·6	25 –J22	16	0·75	>1·0
1·0	8·7–J17·7	3·2	2·0	2·5
2·0	1·6–J11·1	0·95	10·0	5·0
4·0	0·6–J 6·4	0·26	23·9	4·7
8·0	–J 2·75	0·054	93·0	8·3
9·6	–J 1·80	0·033	230·0	7·0

* Actual value used 26·0 μH.

The Q of the whole system commences to become appreciable at 0·6 Mc/s, where 16 μH is the required value of shunt inductance to bring the circuit into resonance. The loss factor in the ferroxcube core was appreciable at this frequency, particularly at high flux levels, and this is illustrated clearly in Fig. 3. The broken line shows the variation of Q with frequency and it can be seen that losses increase rapidly between 0·4 and 0·6 Mc/s, and it is only the effect of the increasing bias current which prevents the Q from becoming too low for satisfactory operation.

An inductance of 0·033 μH is required to bring the Cee into resonance at the highest synchrotron frequency of 9·6 Mc/s. Assuming that a minimum core permeability of 1·3 μ_0 can be reached by biasing, the air-cored inductance of the cavity is required to be 0·026 μH. Fig. 2 shows that the range of permeability obtained from a Grade A3 ferrite core in the tests described above was 900–1·3 μ_0. The upper permeability is sensitive to frequency, flux level and the particular samples tested. The value of 900 μ_0 quoted represents a particular sample and was measured at a very low flux level. In the actual inductance the initial permeability was higher and a range of inductance of 26·0 to 0·033 μH was measured.

This inductance swing is sufficient to tune the Cee of the synchrotron from 0·6 to 9·6 Mc/s. At 0·3 Mc/s the impedance presented by the inductance is 49 Ω which is adequately high, and the inductance has sufficient range to tune the circuit at 9·6 Mc/s.

The maximum flux level at which the ferroxcube could be operated determined the diameter of the core. To drive the Cee at 300 V r.m.s. requires that the inductance can handle the large currents and magnetizing fields involved.

CIRCUITRY AND SERVO-SYSTEM

The large number of ampere turns required to saturate the core were provided by a multi-strand wire, thread many times through the centre of the inductance after the manner shown in Fig. 1. The wire was constructed from thirteen-strand Polyanite-covered copper wire (by Concordia Ltd.) pulled through individual insulating tubes packed tightly into the available space inside the centre conductor. In this way 572 turns of No. 26 s.w.g. wire were passed through the core. The resistance of the winding is 32 Ω.

The bias current through the wire is controlled by a bank of forty 6CD6 beam power tetrodes in parallel. The bias winding is the anode load of the tetrodes. Power is supplied to the system by a 440 V three-phase rectifier set rated to deliver 14 A continuously. The anode current through the valves is controlled in the conventional manner by varying the grid voltage, which is normally held sufficiently negative to cut the valves off. At the start of the acceleration cycle, a positive-going waveform is impressed upon the grids by closing a microswitch synchronized with the synchrotron magnet cycle. The bias current rises to a maximum of about 10 A by the end of the one second acceleration cycle, and is then reduced to zero to wait for the next magnet pulse. Magnet pulses occur at ten second intervals.

Rather than depend entirely on passive elements to time the inductance, a servo-system was constructed. An error signal was derived from the relative phase of the anode current and voltage in the output power triodes of the rad frequency amplifier driving the Cee and inductance. Wh the output system was in resonance, then the impedan presented to the output triodes was resistive and the pha angle between the anode voltage and current was zero. T phase discriminator employed compared the phase of anode voltage with the grid drive voltage which was fou to be closely in phase with the anode current up to 10 Mc

The error signal was taken from the phase detect amplified and fed on to the grids of the bias control tub and in this way the tracking of the radio-frequency syst with the changing acceleration frequency was considerab improved.

PERFORMANCE OF THE INDUCTANCE

The inductance operates in the fringing field of the sy chrotron, which, in the case of the Birmingham machi reaches a peak intensity of 1500 oersted at the location of t inductance. Attempts to operate in this field showed th the tensor properties of the ferroxcube core brought in prominence by this axial field caused spurious modes to excited which overloaded the amplifier. Extensive shieldi has proved necessary to improve this situation.

The ferroxcube employed had a low d.c. resistance and was found necessary to insulate the core from the inn conductor of the coaxial cavity by a thin layer of fluon ta (by Imperial Chemical Industries Ltd.). Unless this pr caution was taken, small pieces of ferroxcube chipped o during handling collected together and formed bridg causing radio-frequency short circuits.

Once the development troubles described above had bee cured, the inductance was put into continuous operation o the synchrotron and has operated satisfactorily for mo than a year. The consistency of performance of the sy chrotron has been improved and more beam is accelerate Under the best conditions the beam is accelerated witho more loss than is caused by the gas scattering early in th acceleration cycle.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. George Guest witho whose loyal help the work described would never have bee completed. Among his other duties, he shouldered most o the work of installing the inductance in the test area durin the short periods when tests were possible. After man trials, he developed a reliable bias winding. The autho wishes to thank Prof. P. B. Moon and other members of th laboratory for helpful discussions and practical assistanc The author also wishes to acknowledge his indebtedness t the D.S.I.R. for a Research Fellowship for the years 1953–5

REFERENCES

(1) Hibbard, L. U. *J. Sci. Instrum.*, **31**, p. 363 (1954).

(2) Blewett, J. P., Blewett, M. H., and Plotkin, M *Rev. Sci. Instrum.*, **24**, p. 800 (1953).

A differential thermal analysis apparatus

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An automatic differential thermal analysis apparatus of high sensitivity is described in detail. The rate of heating is servo-controlled to give any selected value from 6 to 20° C per minute. Curves are obtained directly on an *X–Y* potentiometric recorder. Temperature differences can be detected to within 0·1° C. Reference is made to the application of the apparatus in the study of glass-making reactions.

ferential thermal analysis is the term given to a method nvestigating chemical and physical changes by a tempera- measurement. The sample and an inert reference terial are heated in a furnace at a controlled rate, and the erence in temperature between the sample and inert rence material is measured continuously. Results are ually shown graphically, with these temperature differences tted as ordinates against reference temperatures as cissae. Maxima in such a curve indicate exothermic nges, while minima indicate endothermic changes.(1)

DESCRIPTION OF APPARATUS

The apparatus first used in this laboratory was similar to t described by Berkelhamer.(2) Preliminary work using s first apparatus showed that a much greater sensitivity ould be required in the measurement of the differential mperature in order to use the apparatus to study the course f glass-making reactions.

Some modifications have been described(3) and the present aper describes further improvements which have made the pparatus highly sensitive and capable of measuring minute hermal effects, such as those occurring in quartz and sodium arbonate.(4) The temperature differences can be read to ·1° C and reference temperatures to ±5° C.

The apparatus is now automatic in operation, the selected ate of rise of temperature of the furnace being controlled by an electronic servomechanism. The temperatures of the sample and inert reference materials are measured by platinum/platinum −13% rhodium thermocouples. The differential thermal analysis curve of temperature difference against temperature is recorded directly on the chart of a double potentiometric recorder. In this recorder the pen position is determined by the difference potential produced by the two thermocouples when the sample and reference materials are at different temperatures, and the chart position is determined by the e.m.f. produced by the thermocouple in the reference material. Fig. 1 is a schematic diagram of the apparatus.

Furnaces. Each furnace consists of two concentric refractory tubes and an outer aluminium case fitted into 1 in. Syndanio boards (by Turner's Asbestos Co. Ltd.) which act as end pieces for the furnace as shown in Fig. 2. A $1\frac{5}{8}$ in. diameter hole on the axis of the furnace locates the crucible holder referred to below. The space between the aluminium casing and the outer refractory tube is filled with alumina.

The heating element of platinum–rhodium wire lies on the surface of the inner tube. For its construction a refractory rod of sufficient length is wound with waxed paper over the entire length and of a suitable thickness. The heating element wire is wound on and then coated with wet alumina cement. After drying, the tube is heated slowly to 1500° C and then allowed to cool. The paper burns away during this process and the refractory rod can be removed, leaving a tube of

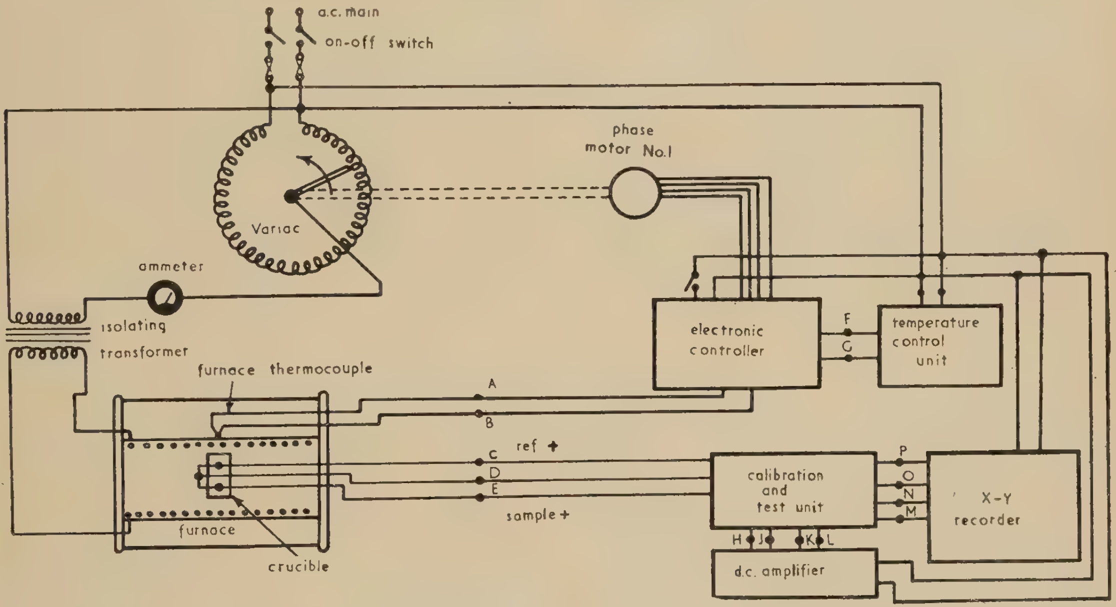

Fig. 1. Functional layout of differential thermal analysis apparatus. (The letters correspond with those on other diagrams)

refractory cement with an internal winding. By the use of this system of internal winding, excessively high temperatures on the heating element are avoided. The space between the outer refractory tube and furnace tube is left unfilled, thus permitting easy replacement of the heating element.

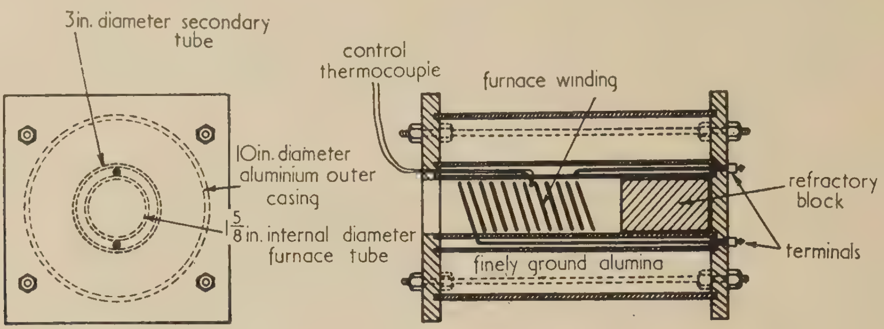
3in. diameter secondary tube
control thermocouple
furnace winding
10in. diameter aluminium outer casing
$\frac{5}{8}$in. internal diameter furnace tube
refractory block
finely ground alumina
terminals

Fig. 2. Constructional details of furnace

Crucible holder. The holder, made from recrystallized alumina, is commercially available, and is made to a design of Roberts and others.$^{(5)}$

Double crucible. The double crucible, made of platinum/rhodium alloy, consists of two similar compartments each about 1 cm^3 in volume, having a common dividing wall. One compartment contains the inert reference material, alumina previously calcined at 1600° C, whilst the other contains the sample under test.

The thermocouple wires, suitably insulated, enter the compartments through small holes in the side walls of the double crucible and leave by similar holes in the opposite wall. This helps to keep each thermocouple junction in the centre of the material in each compartment.

The assembled double crucible and thermocouples are then set in alumina cement, fired to 1200° C and fitted into the well of the crucible holder. This procedure has been found to be important for obtaining consistent results.

FURNACE HEATING AND TEMPERATURE CONTROL

To ensure that the furnace temperature should rise or fall at a uniform rate it was found essential to devise an automatic system of control.

The control system consists of a temperature detection element, a continuously variable potential proportional to temperature and a controlling unit. A thermocouple embedded in the cement of the furnace winding in the region of highest temperature is used as the temperature detection element. The continuously variable potential is obtained from two motor-driven ten-turn potentiometers connected through suitable resistors to a fixed source of e.m.f. The control unit consists of an amplifier providing power to drive a two-phase motor.

The e.m.f. from the thermocouple is opposed by the potential from the ten-turn potentiometers, and the resultant potential difference is fed into the electronic amplifier, which is similar to that used in commercial potentiometric recorders. The output from this amplifier drives the two-phase motor in one direction or the other, depending on the polarity of the difference input with reference to the "earthy" line of amplifier. Through suitable gearing and a clutch, the two-phase motor drives a 2 kVA continuously variable transformer, which supplies power to the furnace winding through a 2 : 1 step-down transformer. The latter transformer isolates the furnace winding from the power supply so th the thermocouple may be earthed to reduce stray potent effects in the input stage of the amplifier; operation is n affected even when the thermocouple touches the winding

An increase in the thermocouple e.m.f. above that of t backing potential decreases the power to the furnace an *vice versa.* The system is a closed servo-loop. Hence th thermocouple e.m.f. follows the variable potential closel and the rate of rise of furnace temperature is controlled the continuously variable potential. When a constant ra of heating is not important, the continuously variab potential may be derived from a simple ten-turn poten meter circuit shown in Fig. 3(*a*). If the potentiometer driven at a constant speed the output voltage will increa linearly with time. Using the circuit of Fig. 3(*a*), the ra of heating falls with increasing temperature. This is becau the sensitivity of the thermocouple increases with increasin temperature. Thus the temperature of the furnace woul rise more slowly with increasing temperature.

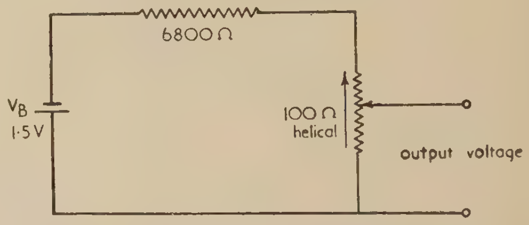

Fig. 3(*a*). Simple variable output circuit giving linear voltage output

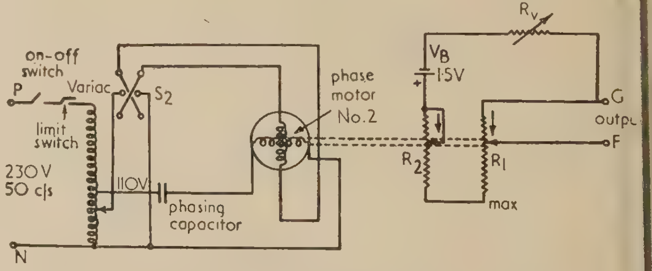

Fig. 3(*b*). Temperature control unit

R_v = 1 kΩ variable + 680 Ω fixed

R_1 = 20 Ω ten-turn potentiometer
R_2 = 680 Ω ten-turn potentiometer

When it is necessary to maintain a constant rate of heatin over a wide range of temperature, the circuit shown i Fig. 3(*b*) is used. Both ten-turn potentiometers R_1 and are driven at the same speed from a variable speed motor and R_2 is at maximum when R_1 is at minimum. The variabl ed motor is a second two-phase motor, one winding of ich is energized from a 110 V a.c. mains through a phasing acitor, while the other is energized from a variable supply 0–110 V. The variable supply controls the speed of the tor, and the polarity of this voltage determines the direction of rotation. Thus the variable supply voltage controls the rate of change of temperature, and the polarity of this voltage determines whether the furnace is being heated or cooled.

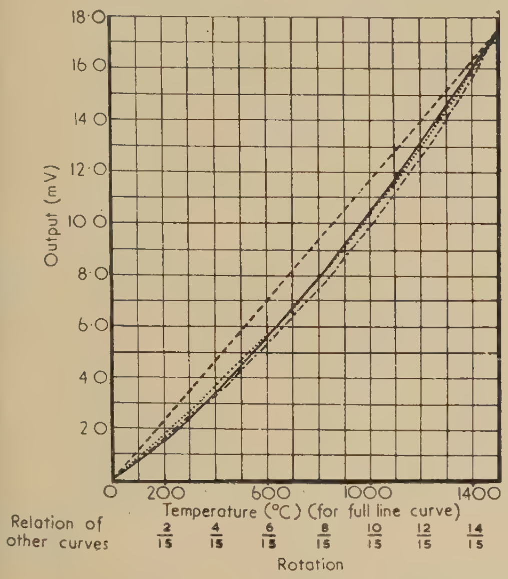

Fig. 4. Curves showing relation between thermocouple temperature and output voltage, and relation between special potentiometric control rotation and output voltage

——— = platinum/platinum −13% rhodium thermocouple e.m.f. *versus* temperature.

. . . . . = output curve using Fig. 3(*b*) and $V_B = 1\cdot54$ V with R_v adjusted to give 17·46 mV across R_1 at maximum, R_2 at minimum.

—·—· = output curve using Fig. 3(*b*) and $V_B = 1\cdot20$ V, with R_v adjusted to give 17·46 mV across R_1 at maximum, R_2 at minimum.

– – – = output curve using Fig. 3(*a*).

Fig. 4 shows the output voltage (dotted curve) obtained from the circuit in Fig 3(*b*) as the sliders are moved across the resistors, and it also shows a thermocouple e.m.f. *versus* temperature curve. The pre-set resistor R_v is set to give 17·46 mV at the output terminals with R_1 at maximum (and R_2 short-circuited by its slider). The curve approaches the thermocouple e.m.f. curve quite closely. The output for the simpler circuit of Fig. 3(*a*) is also shown (dashed curve).

Hence if the sliders of potentiometers R_1 and R_2 in Fig. 3(*b*) are rotated at a constant speed, the voltage produced will make the rate of rise or fall of temperature remain constant.

Temperature measurement. In the apparatus described it was desired to be able to measure temperature differences of the order of 0·2° C or 2 μV voltage difference from the thermocouples. The commercial recorder available had a pen full-scale movement of ±0·5 mV with centre zero, 0·5 mV giving a pen movement of 5 in. Hence the measurement of 2 μV on the pen movement would not be possible without some means of amplification.

The chart had a full-scale movement of 10 in. for 10 mV output, and the output from the reference thermocouple is 10·4 mV at 1000° C and 17·46 mV at 1500° C. To make the chart movement a maximum for each of these temperatures, thus giving two temperature ranges, the output would have to be stepped down by a potential divider to give 10 mV in each case. The final circuit for the measurement of both reference temperature and difference temperature between reference and sample materials is shown in Fig. 5.

The two thermocouples, one in the reference material and the other in the sample, are attached by compensating cable to the three input terminals. The two negative leads are joined together and connected to the terminal *D*. The reference thermocouple positive lead is connected to *C*, and the sample thermocouple positive to *E*.

The resistors R_6–R_9 constitute a potential divider across the e.m.f. from the reference thermocouple, and the values

R_1 = 10 kΩ
R_2 = 1 MΩ
R_3 = 63·55 kΩ
R_4 = 1 kΩ
R_5 = 43·6 kΩ
R_6 = 500 Ω
R_7 = 100 Ω (1500° scale)
R_8 = 300 Ω
R_9 = 100 Ω (1000° scale)
R_{10} = 3·9 kΩ
R_{11} = 10 Ω (*X*-scale)

X_1, X_2 = *X*-calibration

Y_1, Y_2 = *Y*-calibration

SC = standard cell

S_1, S_2 = double-pole, double-throw switch (*Y*-scale)

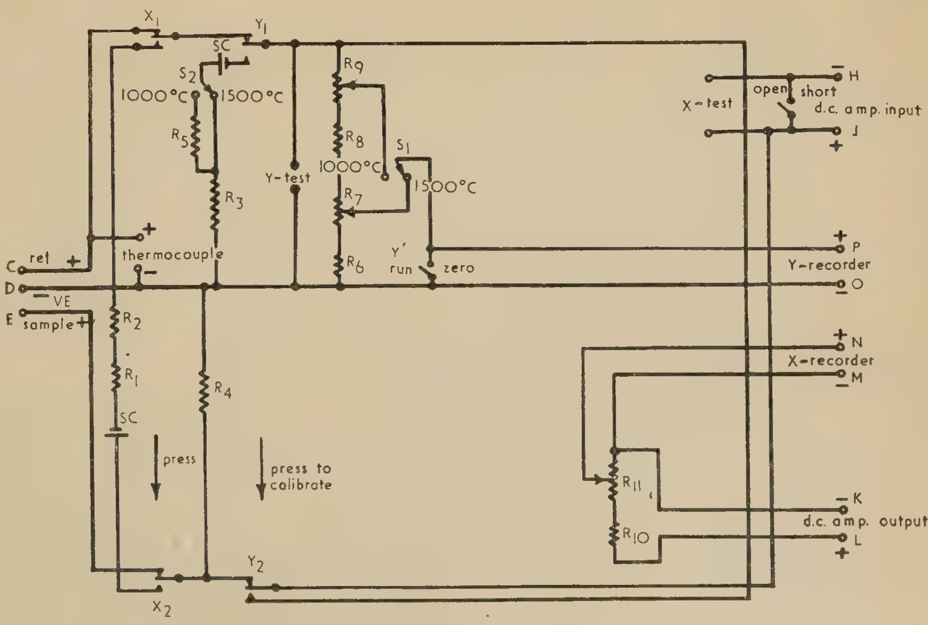

Fig. 5. Calibration and test unit

of the various resistors are so arranged that with the switch S_1S_2 in the 1000° C range position, then 10 mV is applied to the recorder chart movement when the e.m.f. from the thermocouple is 10·4 mV. Similarly, with the switch S_1S_2 in the 1500° C position, 10 mV is applied to the recorder chart movement when the thermocouple e.m.f. is 17·43 mV. In this arrangement the chart moves through 10 in. for 1000° C or 10 in. for 1500° C. In the former case a 1 in. chart movement equals 1·04 mV, and in the latter 1 in. movement equals 1·743 mV. The chart movement may be calibrated from these details in degrees Centigrade.

Resistor R_4, equal in value to the sum of resistors R_6 to R_9 is placed across the sample thermocouple to present equal loading to both thermocouples. If the loading were not equal, a differential voltage would be applied to the pen movement of the recorder, which would increase with increasing reference temperature[3] but would not be due to unequal heating of the reference and sample materials.

The difference voltage due to the difference in temperature between the two thermocouples is applied to a commercial amplifier (Pye d.c. microvoltmeter, Cat. No. 11341/11351).

The amplifier produces a direct current output, the amplitude and direction of which is proportional to the amplitude and polarity of the input voltage. The output current is passed through the resistor chain R_{10} and R_{11} in Fig. 5.

Variation in sensitivity is achieved by two means, firstly by altering the gain switch on the amplifier and secondly by tapping off a variable voltage from resistor R_{11}. The variable voltage is applied to the pen movement of the recorder. In this way any voltage amplification from 1 to 100 may be obtained. Thus, full-scale deflexion of the pen of the recorder may be produced by a minimum voltage difference from the thermocouples of $\pm 5\ \mu$V, which represents approximately $\pm 0{\cdot}5°$ C temperature difference. In practice, full-scale deflexion of the pen is produced by a voltage difference from the thermocouples of $\pm 50\ \mu$V representing $\pm 5°$ C full-scale movement, or 1° C temperature difference per inch.

Calibration. The recorder is calibrated by introducing fixed standardized potentials into the two circuits. By depressing push-button Y_1Y_2 (Fig. 5) a potential of 9·36 mV or 15·62 mV derived from a standard cell and resistors R_5 and R_3, or R_3 alone, is applied to the chart movement of the recorder, the particular e.m.f. being decided by the position of switch S_1S_2. While this button is depressed R_9 is adjusted with S_1S_2 in the 1000° C position, and R_7 is adjusted with S_1S_2 in the 1500° C position to move the chart through 9 in. During this test the input to the microvoltmeter is short-circuited and the thermocouples are disconnected from the circuit. The chart deflexion input can be short-circuited to adjust the zero position of the recorder chart to any particular inch line on the chart.

The pen deflexion of the recorder may be calibrated by depressing the push-button X_1X_2 which applies a potential of 40 μV derived from a standard cell and resistors R_1R_2 to the input of the microvoltmeter. Here, also, the thermocouples are disconnected. With the X_1X_2 switch depressed, the output voltage from the amplifier which is applied to the recorder may be adjusted by variable resistor R_{11} and the gain switch to give the amplification required. The recorder pen position may be set at any desired position on the chart at the beginning of a differential thermal analysis run by means of the microvoltmeter "zero control." In this way it is possible to plot a number of runs on one piece of graph paper.

DETAILS OF USE

Samples. All sample materials are ground to pas 100-mesh B.S.S. sieve, the actual grain size depending on th type of investigation being carried out. Normally n previous heat treatment is given to the samples, unless th conditions of test make this desirable. The referenc material, calcined alumina, is sieved to pass a 100-mes sieve, and to be retained by a 200-mesh B.S.S. sieve.

Loading of double crucible. The thermocouples are inserte and cemented as described above. The outgoing leads ar covered by alumina sleeving from just inside the crucible t the outside of the crucible holder, in order to eliminate th risk of short-circuiting the thermocouple leads in the holde and crucible.

One side of the double crucible is filled with alumina a the reference material, and tamped down firmly by a glas rod. More calcined alumina is added and tamped dow until the crucible is filled. The surface is then smoothed of The sample material is filled into the other crucible in similar manner.

Setting up the apparatus. The crucible holder, complet with packed double crucible, is placed in the furnace so tha the square end of the holder butts against the Syndanio en piece of the furnace. The three thermocouple leads ar connected to the three terminal block marked *C*, *D* and (Fig. 5), below the furnaces. The Pye microvoltmeter inpu is short circuited by a switch, as is also the *Y*-axis inpu The recorder clutch is released and the chart is set so tha thick horizontal line coincides with the point of the pe The *Y*-axis switch is opened and calibrated as described i the section on calibration. The "temperature range" switc S_1S_2 is set to the required range.

The two ten-turn potentiometers R_1 and R_2 are turned t zero and then turned until the power Variac phase moto ceases to rotate. They are then advanced a further twent divisions. The rate of heating is set by the "temperatur gradient" control which controls the speed of the drivin motor. The "temperature rising/falling" switch [S_2, Fig 3(*b*)] is set to "rising." The clutch of the power Variac i engaged and the current flowing into the furnace is allowe

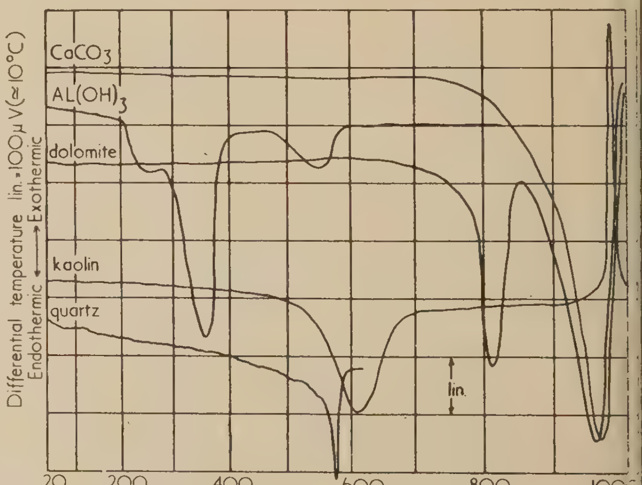

Fig. 6. Differential thermal analysis of some glass-making materials

Differential temperature for quartz curve only: 1 in. = 10 μV (≃ 1° C) ise to 6 A. The motor driving the two ten-turn potentio- ers is then switched on and the clutch is engaged. The rovoltmeter input and the *Y*-axis input are unshorted. pen of the recorder is put in contact with the chart.

Vhen the maximum temperature required has been hed, the continuously variable transformer supplying ver to the furnace is returned to zero and the sample wed to cool down.

USE OF APPARATUS

he curve drawn by the recorder is a true differential mal analysis curve, and there is no need to replot the ve in any way. The curves may be photographed directly, s eliminating errors which might be introduced by having eplot them. Temperature lines may be drawn over the ves from the knowledge that 1 in. movement is equal ·04 mV on the 1000° C range or 1·74 mV on the 1500° C ge.

ifferential thermal analysis curves of some glass-making erials are shown in Fig. 6. The apparatus is sensitive ugh to detect temperature differences of the order of ° C. For a 1 g. sample of quartz, the recorder shows a exion of about 2·5 in. at 573° C where the α–β inversion es place. The temperature of a peak can be read to an uracy of ±5° C.

CONCLUSIONS

he high degree of sensitivity of the apparatus described ove might make it of value in fields of research other than the study of clay minerals and glass melting. Preliminary experiments of certain chemical reactions have indicated that the method of differential thermal analysis can have a much wider application.

The apparatus has proved to be very reliable and results obtained have a high degree of precision, the rate of heating being maintained to within ±1° C per minute over the working range of temperature.

ACKNOWLEDGEMENTS

The author wishes to thank Miss F. Stretch for preparing the diagrams and the Directors of Pilkington Bros. Ltd. for permission to publish this paper.

REFERENCES

(1) Smothers, W. J., Chiang, Y., and Wilson, A. *Bibliography of Differential Thermal Analysis* (University of Arkansas, 1951); Mackenzie, R. C. (Ed.). *The Differential Thermal Investigation of Clays* (London: Mineralogical Society, 1957).

(2) Berkelhamer, L. H. *U.S. Bur. Mines Tech. Paper* 664 (1945).

(3) Wilburn, F. W. *J. Soc. Glass Technol.*, **38**, pp. 371–382 (1954).

(4) Jaffray, J., and Martin, P. *C.R. Acad. Sci. (Paris)*, **236**, pp. 1755–1756 (1953).

(5) Roberts, A. L., Grimshaw, W., and Heaton, E. *Trans Brit. Ceram. Soc.*, **44**, p. 69 (1945).

The effect of variations in ambient temperature upon the optical alinement of an X-ray fluorescence spectrometer

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During proving tests made on an X-ray fluorescence spectrometer, it was found that variations in ambient temperature produced a significant effect upon the dispersion of the instrument. Experimental evidence indicated that this was due to changes in the interplanar spacing of the diffracting crystal. The magnitude of the effect is shown to be in good agreement with theoretical considerations.

Since the angular dispersion is an inverse function of $d\cos\theta$, the effect is most marked at high Bragg angles. The significance of the observed changes in angular dispersion, in relation to the accuracy of analysis, is pointed out.

ray fluorescence spectroscopy is being increasingly used analysis. The technique consists of exposing a sample to intense incident beam of "white" X-rays, causing it to nit secondary X-rays of wavelength characteristic of the ments present. These fluorescence X-rays are dispersed means of a diffracting crystal, and detected by a device ch as a Geiger or proportional counter.

The relationship governing the variables of the dispersing stem is given by the Bragg equation:

$$n\lambda = 2d\sin\theta \qquad (1)$$

here d is the crystal interplanar spacing, λ the wavelength of e radiation, n its order of reflexion and θ the angle between e fluorescence radiation and the crystal face. The crystal d detector are geared together such that the detector tates with twice the angular velocity of the crystal. Thus, en the crystal face makes an angle θ with the fluorescence diation, the detector is automatically positioned at angle 2θ. is obvious from the equation that a change in the inter- anar spacing of the diffracting crystal would produce an gular "shift" in the X-ray spectrum, which would be apparent as a change in the 2θ angles at which the characteristic fluorescence radiations were recorded. Furthermore, the magnitude of the displacement would increase with increasing 2θ angle.

Theoretically, a change in interplanar spacing may be produced by thermal expansion or contraction of the crystal material. In this case, the displacement at any particular angle would vary directly in relation to temperature. Despite the recent increase in popularity of this technique as a means of analysis, no mention has been made in the literature of the effects produced by fluctuations in ambient temperature upon the optical alinement of an X-ray fluorescence spectrometer. These could seriously affect the quantitative accuracy of many of the automatic instruments which have been developed for works- and process-control purposes, since these instruments either employ a number of fixed X-ray channels, each with its own diffracting crystal set at a specific angle, or record radiations at a number of pre-programmed 2θ values. Consequently, during the proving tests on a recently installed instrument it was decided to include an investigation of the effects of variations in ambient temperature.

APPARATUS

The X-ray fluorescence spectrometer used in this investigation was of the type XRD-5 (made by the International General Electric Co.), incorporating a Machlett type AEG-50 tungsten target tube and operating with a 50 kV, 50 mA (maximum) power supply. The detector was a standard No. 4 SPG flow-type counter tube using a gas mixture consisting of 90% argon and 10% methane. Lithium fluoride and quartz diffracting crystals were available. The 2*d* values quoted for these crystals at 20° C were, respectively, 4·0269 and 2·7567 Å.

EXPERIMENTAL TECHNIQUE

The effect of variations in ambient temperature upon the optical alinement of the spectrometer was first investigated, using a diffracting crystal of lithium fluoride and a target sample of pure tungsten. Tungsten was chosen for this investigation because the *L*β1 line of this element occurs at a wavelength which may be conveniently recorded at reasonable intensity in each of the first three orders of reflexion from a lithium–fluoride crystal.

Starting from 17° C, the temperature of the laboratory was raised slowly by means of auxiliary heaters, and the entire instrument was allowed to attain thermal equilibrium at several convenient values of ambient temperature, up to a maximum of about 25° C. The angular positions of all three orders of the chosen line were determined at each equilibrium temperature: to ensure a high level of accuracy for these measurements the angles were determined from plots of the line profiles. After attaining the maximum temperature used, the laboratory was allowed to cool down and the 2θ angles were re-checked during this process. The experiment was then repeated, using a quartz crystal. The interplanar spacing of this crystal was less than for lithium fluoride, so that observations were restricted to the first and second orders of the tungsten Lβ1 line. Throughout the entire investigation the thermometer was situated 1 in. away from the crystal.

Having thus made a precise determination of angular "shift" in relation to temperature over the normal working range of Bragg angles, the practical effects of such shifts, on actual analyses, were assessed from a plot of the profiles of certain of the lines likely to be used for analysis.

For the purposes of this investigation the maximum tolerable error in the measurement of line intensity (peak count) was assumed to be 1%. A plot of the line profiles, therefore, made possible an estimation of the maximum permissible angular distance from the peak at which each line could be measured before the intensity dropped 1% below the peak value. By referring to the precise measurements of angular shift with temperature which had previously been made, it was possible to estimate the tolerable temperature variation for the lines in question.

DISCUSSION OF RESULTS

Variation of angular dispersion with ambient temperature. The variations of 2θ angle with temperature for a lithium-fluoride diffracting crystal are shown graphically in Fig. 1. It will be seen that for all three orders an angular shift was observed, and that this increased with rise in temperature and with magnitude of the 2θ angle. The shift was such as to displace the tungsten lines to smaller 2θ angles for rising temperatures. The maximum shift observed occurred for the third-order line (2θ value 145·64° at 20° C): it was recorded as an angular shift of 1·4 scale divisions (0·014 of a degree) per °C change in temperature. The corresponding shi for the second- and first-order lines were, respective 0·0033° and 0·0016° per °C, a result which is consistent wi an increase of crystal interplanar spacing with rise temperature.

Observations were also made using a quartz diffracti crystal. The angular shift per degree Centigrade change temperature was found to be less than for the lithium–fluori crystal, and for practical purposes the effect could saf be neglected.

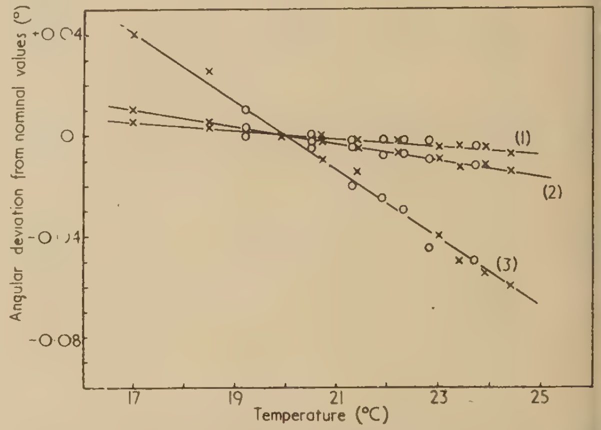

Fig. 1. Variation of 2θ angle with temperature, measur for the *L*β1 line of tungsten

× = rising temperature. ○ = falling temperature
Curve (1), 1st order ($2\theta_{20}$ = 37·14°); curve (2), 2nd ord ($2\theta_{20}$ = 79·12°); curve (3), 3rd order ($2\theta_{20}$ = 145·64°).

Effect of changes in angular dispersion upon accuracy analysis. The profile of the Kα, second-order, X-r emission line of cobalt (2θ value 125·38° at 20° C), in th region of its peak, is shown in Fig. 2. Results for a nick and for a titanium line produced similar profiles, even thou their absolute peak values differed considerably. The ter perature change required to produce a known angular shi at a given 2θ angle may be determined from data based the values used for Fig. 1. Hence, it was calculated that

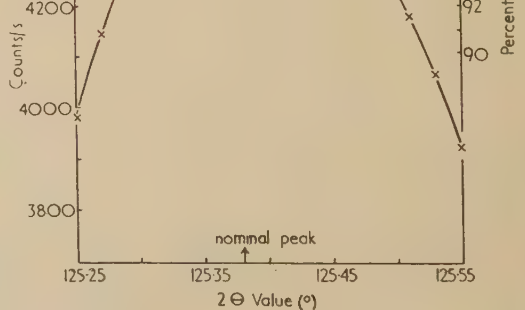

Fig. 2. Peak profile of cobalt Kα, second order, X-ray line

er to obtain a line-intensity reading within 1% of the peak ue when the detector is positioned at the nominal 2θ angle culated for 20° C), the ambient temperature must be kept he range $(20 \pm 9)°$ C for a line which occurs at 86°, in range $(20 \pm 6)°$ C for a line at 96°, and in the range $\pm 3{\cdot}5)°$ C for a line at 125°.

he profiles of all three selected lines were measured using same sample and with the electrical power supplied to X-ray tube maintained at a constant level. The per- tage deviation from peak value, at a given angular distance n the peak, was much the same for all the lines, showing t the shape of the line was independent of the absolute intensity. This being so, the calculation that the tem- ature must be kept in the range (20 ± 2) °C for accurate asurement of the second-order Kα line of iron ($2\theta =$ ·25°) is reasonable.

THEORETICAL CONSIDERATIONS

ince $n\lambda$ is constant for a particular line in a given order, erentiation of equation (1) with respect to temperature T, es

$$\alpha \tan\theta = -\partial\theta/\partial T \qquad (2)$$

ere α is the coefficient of thermal expansion of the crystal terial.

The most accurate determination of the change in 2θ value h temperature is that for the third order $L\beta 1$ line of ıgsten ($\partial\theta/\partial T = -0{\cdot}014°$ per °C), since the angular ınge per degree Centigrade is greatest and therefore most ily measured. The observed 2θ value for this line, at ° C, was 145·64°.

Hence, substitution for θ and $\partial\theta/\partial T$ in equation (2) gives a efficient of thermal expansion (linear) for lithium fluoride 37×10^{-6} per °C, which agrees fairly well with that oted by Adenstedt.(1)

The coefficients of thermal expansion, at room temperature, several of the diffracting crystals normally used for X-ray ectroscopy are given below.

Crystal materia	*Coefficient (per °C)*
rock salt(2)	$40{\cdot}40 \times 10^{-6}$
quartz(2)	$7{\cdot}97/13{\cdot}37 \times 10^{-6}$
topaz(2)	$4{\cdot}72/8{\cdot}36 \times 10^{-6}$
lithium fluoride(1)	34×10^{-6}

It will be appreciated that the use of a diffracting crystal possessing a lower coefficient of thermal expansion than lithium fluoride will result in smaller temperature-induced angular shifts: this was observed for quartz. On the other hand, the use of a crystal of higher thermal expansion will result in increased susceptibility of the instrument to temperature change.

CONCLUSIONS

Variations in ambient temperature produced a significant effect upon the angular dispersion of the X-ray fluorescence spectrometer examined. The experimental evidence indicated that the effect was due to changes in the interplanar spacing of the diffracting crystal: the influence of temperature was most marked at high Bragg angles.

If the inaccuracy in the measured line intensity is to be less than 1% when the detector is positioned at the nominal 2θ angle for the line concerned, the maximum permissible temperature variation (about a 20° C mean) for a lithium–fluoride diffracting crystal is $\pm 10°$ C at $2\theta = 80°$, but is only $\pm 2°$ C at $2\theta = 145°$. For crystals of lower thermal expansion, greater variations in ambient temperature can be tolerated.

Of the observed effects, only the variation in angular dispersion is capable of general quantitative application, since the magnitude of its effect upon the accuracy of line-intensity measurement is a function of the X-ray line profile. Since this, in turn, is dependent upon the effective resolving power of the instrument, it is to be expected that the precise effect of temperature on analytical precision will vary for different instruments. The line width at half-peak intensity obtained with this particular equipment, using a lithium–fluoride crystal, was about 0·75°. For an instrument with a greater resolving power the off-peak intensity will fall more rapidly with increasing distance from the peak, and the dependence of the instrument upon temperature will therefore be increased.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Adenstedt, H. *Ann. Phys.* (*Leipzig*), **26**, p. 69 (1936).
(2) *Handbook of Chemistry and Physics*, pp. 2063–4 (Cleveland, Ohio: Chemical Rubber Publishing Co., 1957).

X-ray spectrographs for rapid X-ray fluorescence analysis with photographic recording

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Curved crystal spectrographs are described covering the range from potassium to uranium. With the higher speed model simultaneous recording of spectra between 0·5 to 2·5 Å or 1·5 to 3·75 Å is possible and minor constituents at the 0·1% level can be detected. A higher sensitivity version (down to 0·001%) employs a scanning device for covering the required wavelength range. With suitable comparison standards the instruments may be used for quantitative as well as qualitative analysis.

apid advances have been made in recent years in the evelopment of X-ray fluorescence spectrography as an ıalytical technique. The availability of modern counting chniques and of high intensity X-ray sources for the imulation of spectra has led to its use in many fields.(1–3) some research groups, however, where these techniques e not required for routine or frequent application, the cost of an adequately stabilized fluorescence analysis unit involving counter equipment is prohibitive and in such cases a cheaper and simpler method would be invaluable. For several years this laboratory has employed fluorescence analysis techniques involving photographic recording in a wide range of applications and has developed a number of curved crystal spectrographs which can be used with any standard X-ray generator, preferably of the crystallographic type. For qualitative work these spectrographs compare favourably in performance with the counter spectrometer and indeed present certain advantages. For precision quantitative analysis the limitations are imposed primarily by the difficulties of accurate calibration and measurement of film densities, and the accuracy attained is somewhat lower than that obtainable with the best counter techniques. Nevertheless with careful standardization the method has proved invaluable for quantitative as well as for qualitative analysis.

PRINCIPLES OF THE DESIGN

Apart from its cheapness, the main potential advantage of film recording lies in the possibility of designing spectrographs which, by recording a wide range of wavelengths simultaneously, can effect a considerable economy in time in certain applications compared with the point by point scanning involved in counter techniques. To achieve this and at the same time ensure an acceptable speed of recording it is essential to use a curved crystal focusing analyser. The cameras described in this paper are based on either the Johansson(4) or Cauchois(5) focusing principles in which a curved crystal diffracts all acceptable wavelengths to foci which lie on a circle of half the radius of curvature to which the analysing crystal has been bent.

In some applications of fluorescence analysis, speed of recording is the primary consideration, while in others the limits of detection are more important. In either case it is necessary to design the spectrograph so that:

(*a*) a high proportion of the total intensity of the excited radiation is incident on the analysing crystal and contributes to the recorded line intensity; and

(*b*) that the intensity losses in the analysing crystal and in the camera are reduced to a minimum.

The first of these requirements demands the use of a curved crystal analyser of large angular aperture which will effectively focus the fluorescent radiation without the use of collimating slits. Placing the specimen as close to the analysing crystal as possible is also important in ensuring the maximum incidence of fluorescent radiation on the analyser. Since vacuum operation is inconvenient for general applied work, the second requirement necessitates the reduction of the dimensions of the camera to a minimum consistent with adequate resolution of the diffracted beams. The reduction of the spectrograph size involves the use of analysing crystals which can be bent plastically and it is a fortunate circumstance that sodium chloride and more particularly lithium fluoride crystals are both efficient reflectors of X-rays.

The adoption of a system involving a stationary wide aperture focusing analyser with only limited collimation of the fluorescent radiation while ensuring a high speed of recording and maximum range of recorded wavelengths inevitably introduces a loss in sensitivity due to the increase in scattered radiation recorded on the film. Where greater sensitivity of detection is preferred to speed of recording it is possible, by the introduction of limited collimation and oscillating the spectrograph, to increase the sensitivity of detection a hundredfold to 1 in 10^5 in favourable cases. Both types of camera have been developed and are described fully in the following sections.

DETAILS OF DESIGN

Basic spectrograph unit. The basic design of the spectrograph unit is common to both types of apparatus which have been developed. In the Johannson system the locus of f of the diffracted beams has the same centre and radius curvature as the ground surface of the analysing crystal, a in the Cauchois method the crystal surface touches the fo circle. This permits the very simple and rigid design of spectrograph body shown in Fig. 1(*a*) in which the analysi crystal is cemented in position on the semi-cylindrical surfa of the spectrograph which locates the recording film. T crystal and camera body have a radius of curvature 57·15 mm ($2\frac{1}{4}$ in.).

In the Johannson technique the specimen is located shown in Fig. 1(*b*) and the beam of excited radiation can limited by the adjustable aperture *A*. When this is fu open the angles of incidence of the fluorescent radiation c the crystal cover the range from 20° to 70° and under thes conditions a range of wavelengths from about 1·5 to 3·75 can be recorded with a single setting of the spectrograp Radiation of wavelength less than about 1·5 Å, howeve will be incident on the film surface at so small a grazing ang that line broadening and, if double-coated films are use line doubling will result. To obviate this, it is convenien when analysing for short wavelengths to replace th Johannson crystal by a Cauchois crystal in which a thi bent crystal lamina reflects a transmitted beam from plane which are radial to the surface of the crystal. The locatio of the specimen and the ray paths are thus indicated i Fig. 1(*c*). The full range of this instrument is about 0·5 t 2·5 Å. The two types of spectrographs are designate reflexion and transmission spectrographs respectively.

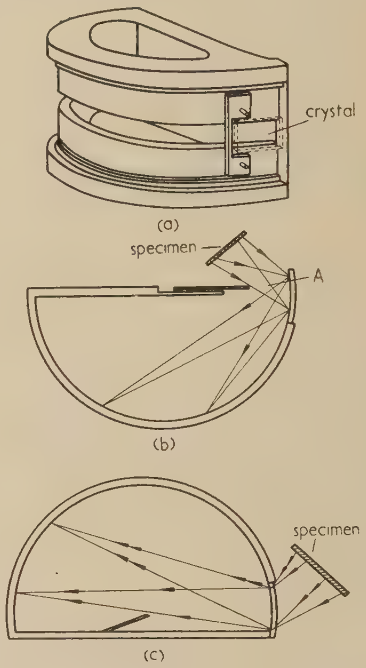

Fig. 1. Basic design of spectrographs
(*a*) shape of spectrograph unit;
(*b*) geometry of reflexion spectrograph;
(*c*) geometry of transmission spectrograph.

For the analysing crystal no material superior to lithiu fluoride has been encountered. It is mechanically strong easily deformed plastically at 400 to 500° C and is unaffecte by exposure to X-rays or to the atmosphere. It is readil obtainable in large single crystals which cleave easily t liminae as thin as 0·1 mm. The intensity of reflexion fro the (200) planes is very strong and although samples diffe atly in the perfection of their structure it has been found ssible to select crystals which give adequate resolution for ctrographs of these small dimensions. The spacing of (200) planes is nominally 2·029 Å and this is suitable for analysis of all elements from potassium to uranium, using spectra for elements lighter than tellurium and L spectra heavier elements.

Johannson-type focusing crystals are prepared by plastically forming laminae to twice the camera radius and then nding to the final radius, while Cauchois type crystals are epared by merely plastically bending to twice the camera dius.

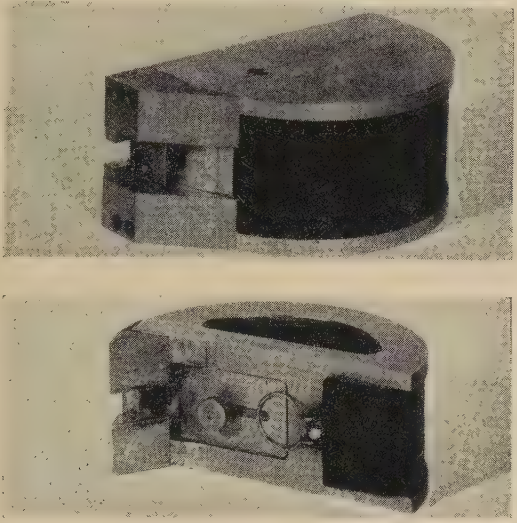

Fig. 2. Wide angle reflexion and transmission spectrographs

The wide angle spectrograph. The wide angle spectro- aph is derived from the basic design described above by e attachment of a specimen holder as shown in Fig. 2, here the form of holder used for the reflexion and trans- ission cameras may be seen. The inclination and location f the specimen bearing surface are designed to ensure that ith the appropriate size of specimen (covering at least mm of the length of the specimen slot) it is possible with a xed setting of the spectrograph to record radiation from he elements potassium to uranium. The only precaution ecessary in locating the spectrograph in relation to the -ray tube is to ensure that the primary beam does not trike the edges of the aperture over which the specimen is ounted nor any part of the apparatus which could give ise to scattered radiation entering the spectrograph directly.

For wavelengths greater than about 2 Å the reflexion pectrograph is necessarily used and is normally enclosed in vacuum chamber fitted with a thin Mylar window to admit he primary radiation.

Since the direct beam cannot be recorded to provide a true ero a fiducial line is necessary. This may be conveniently erived from a spectral line in the primary radiation which s scattered on to the analyser by the specimen or by the ddition of a standard substance to the specimen; it may lso be introduced by a double exposure technique in which he unknown specimen is replaced by a standard specimen.

The oscillating spectrograph. The large aperture of the ide angle spectrograph permits too much incoherently cattered radiation to reach the film to give the high line to ackground ratio required for the detection of less than about 1 part in 1000 of a minor constituent and where sensitivity of detection is of more importance than speed of recording it is desirable to reduce this scatter by additional collimation. This necessarily restricts the range of angles of incidence of the fluorescent radiation on the analyser for any one setting of the spectrograph, and it becomes essential to mount the specimen separately from the spectrograph unit and to obtain the range of angles of incidence required by angular oscillation of the latter.

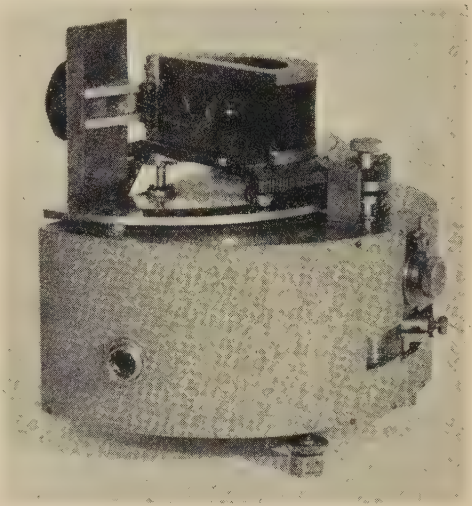

Fig. 3. Oscillating reflexion spectrograph

The general arrangements for reflexion work are shown in Fig. 3. The wedge-shaped specimen mounting is fixed to the base plate of the instrument so that the primary X-ray beam incident on the specimen at an angle of roughly 70°. The fluorescent beam from the specimen is taken off at an angle of 20°, i.e. approximately parallel to the axis of the X-ray tube and passes through a 3 mm wide collimator which forms an integral part of the specimen holder. The axis of the collimated beam intersects the axis of rotation of an oscillating quadrant platform. The two types of spectrographs can be mounted interchangeably on this quadrant and are located by metal dowels so that the centre of the analysing crystal is vertically over the axis of rotation of the quadrant platform. A graduated scale on the circumference of the quadrant indicates the angle between the axial ray of the collimated beam and the (200) planes of the crystal for any setting of the quadrant. A clutch enables the quadrant to be freed and swung into any desired position and then locked to an oscillating mechanism housed in the base of the stand. This mechanism, operated by an electric motor and reversing switches, may be set to oscillate the quadrant at a constant angular velocity of about 20°/min over any desired amplitude from 1° to 20°.

The oscillating spectrograph has to be set to receive a particular wavelength or group of wavelengths, and the appropriate setting is derived from tables of the Bragg angles at which the principal spectral lines of the elements are reflected from the (200) planes of lithium fluoride. The curvature of the crystal and the relatively wide aperture of the collimator, however, ensure that the setting of the spectrograph for the recording of a particular line is not critical and in general the spectra of several consecutive elements can be recorded at one setting. When it is desired to record a wider range of wavelengths the spectrograph is oscillated over the appropriate range of angles.

A fiducial line for film measurement may be obtained in the same manner as with the wide angle spectrograph.

MEASUREMENT AND INTERPRETATION OF FILMS

Fast X-ray film of the non-screen type is suitable, and single-coated film is obviously advantageous in a spectrograph of this type. If slower and more contrasty emulsions are used there is a small gain in resolution but in general practice this is not necessary and is off-set by the loss of recording speed.

All film measurements are made with a transparent scale graduated in degrees Bragg, referred to as the θ scale. The relative positions of the recorded lines can be measured with sufficient accuracy using this scale and more elaborate devices are not necessary. Over the short film lengths involved shrinkage corrections can be neglected.

From the θ values the elements present can be identified by means of the table of Bragg angles already mentioned. It is sometimes found that lines other than (200) reflexions are recorded, but even when this complication arises it is not difficult to identify these unwanted lines. Ideally identification would be sought by means of the wavelength calculated from the lattice spacing of the reflecting plane, the Bragg angle and the order of diffraction. In the case of these parasitic lines none of these factors may be known with certainty, but only that an unknown combination of them has produced a line in the observed position. However, the possible combinations are limited by the geometry of the crystal and by the fact that the wavelength must be that of a spectral line of an element. If the observed θ angles of the spectral lines do not coincide with any recorded in the tables then it must be assumed that they are higher order spectra from the (200) planes or reflexions from other sets of planes of the same zone. The charts in Figs. 4 and 5 have been prepared on the basis of these restrictions and are used to identify unwanted lines.

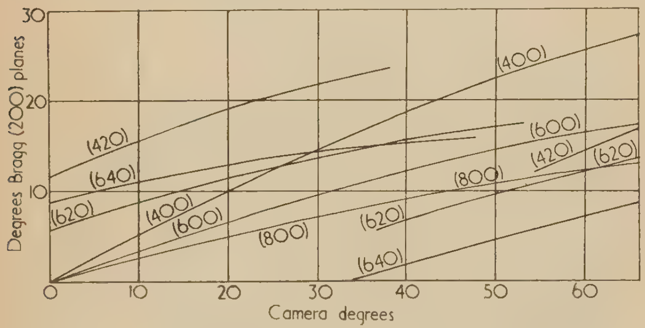

Fig. 4. Chart for the identification of parasitic reflexions

If such a line occurring at an angle θ' (as measured by the scale) is a reflexion from the (*hkl*) planes of the analysing crystal, it may be identified by means of the chart shown in Fig. 4 by finding the point on the appropriate (*hkl*) curve corresponding to θ'. The ordinate of this point gives the angle at which the same wavelength would be reflected from the (200) planes of the crystal, and the table of Bragg angles can be used to identify the line. Identification is considered satisfactory if every line can be accounted for as a line characteristic of a possible element and no significant absences are observed.

The identification of parasitic reflexions can be further simplified in the case of the oscillating spectrograph by defining an "acceptance angle" of the spectrograph. When the spectrograph is positioned at a nominal Bragg (200) angle of θ, the angular aperture of the collimating system permits the recording of lines with (200) Bragg angles of $(\theta \pm \beta)$. This range of angles is readily determined experimentally. If in addition the spectrograph is oscillated over an angular range of $2\,\alpha$, then all wavelengths appropriate to (200) Bragg angles between $(\theta + \alpha + \beta)$ and $(\theta - \alpha - \beta)$ may be recorded. This range of angles may be termed the "acceptance angle" and the extreme values of the range the "acceptance angle limits." If in Fig. 5 we construct a triangle by joining the point on the top scale defined by the measured θ scale value to points on the bottom scale defined by the acceptance angle limits, then the resulting triangle will enclose and define on the middle scale the point or points corresponding to those planes which alone could give a reflexion in the observed position. This method applies only to the oscillating spectrograph.

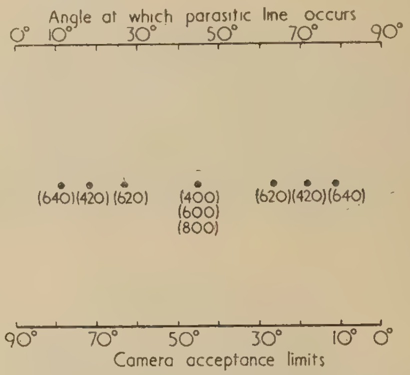

Fig. 5. Chart for the identification of planes able to give a reflexion at a given angle

PRACTICAL APPLICATIONS AND LIMITATIONS OF THE SPECTROGRAPHS

These spectrographs have been used in a wide range of applications such as the following:

(*a*) Identification of unknown materials, frequently as an aid to X-ray diffraction analysis, particularly where amorphous or imperfectly crystalline components were present or insufficient material was available for effective diffraction analysis. Typical examples were identification of amorphous selenium and the analysis of specimens of a microgram or less.

(*b*) Rapid differentiation between materials of similar composition. In this instance it has been possible to distinguish between samples of Nimonic-type alloys where the titanium contents were 0·1% and 0·4%.

(*c*) Detection and estimation of impurities. Typical examples of this type of work involved the estimation of 0·02% of chromium in molybdenum and of 0·2% of vanadium in stainless steels.

(*d*) The estimation of the thickness of thin surface coatings. By the comparison of the effective fluorescent intensity from the coating and the substrate it is possible to determine the thickness of the coating. This technique has been particularly successful in the estimation of the electrodeposited chromium or iron or steel specimens when the thickness was in the range of 0·1 to 5 μ. No stabilization of the X-ray output is required.

The sensitivity of detection of the wide angle spectrograph has been assessed as of the order of parts per thousand and that of the oscillating spectrograph as 1 in 10^5. However, the speed of recording and the accuracy of analysis depend on the nature of the specimen to be analysed. The particular ment sought, the concentrations and absorption coefficients the other constituents present and the possibility of mutual orescence are primary factors which affect the accuracy of alysis. Again the spectral composition of the primary am is an important factor. This is illustrated by the fact at when analysing for iron $K\alpha$ the exposure is longer hen using primary radiation from a silver anode than from copper target; on the other hand analysis for molybdenum arrants the use of a silver anode.

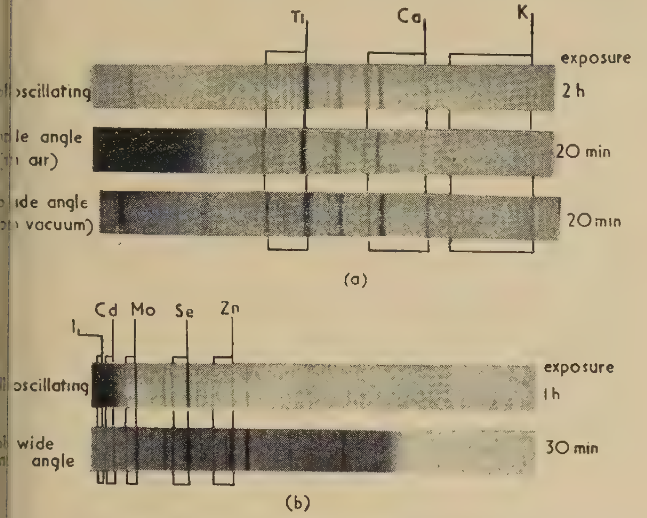

Fig. 6. Comparison of performance of wide angle and oscillating spectrographs
(*a*) Reflexion spectra.
(*b*) Transmission spectra.

Because of these dependencies and the wide variations in the type of specimen it is not possible to give reliable estimates of exposure times for particular sensitivities but the spectra reproduced in Fig. 6 will give the order of magnitude and range of recording speeds. Fig. 6(*a*) compares the speeds of recording of the oscillating reflexion oscillograph, the wide angle spectrograph and the wide angle spectrograph in vacuum when the specimen consisted of approximately equal parts by weight of titanium, calcium and potassium. The exposure times, with primary radiation from a copper target at 40 kV, 16 mA were respectively 2 h, 20 min, 20 min. The higher intensity recorded with the vacuum spectrograph is clearly shown. Fig. 6(*b*) compares spectra obtained with the oscillating and wide angle spectrographs with a specimen which consisted essentially of equal parts of iodine, cadmium, molybdenum, selenium and zinc. The exposure times were 1 h and 30 min respectively with primary radiation at 60 kV, 10 mA from a copper anode.

As in all X-ray fluorescence analysis techniques, whether by counter equipment or film recording, the accuracy of estimation depends on the preparation of known standards.

ACKNOWLEDGEMENT

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REFERENCES

(1) *A.S.T.M. Special Technical Publication No.* 157 (Philadelphia: A.S.T.M., 1954).
(2) Birks, L. S., Brooks, E. J., and Friedman, E. *Analyt. Chem.*, **25**, p. 692 (1953).
(3) Koh, P. H., and Caugherty, B. *J. Appl. Phys.*, **23**, p. 427 (1952).
(4) Johannson, T. *Naturwiss.*, **20**, p. 758 (1932).
(5) Cauchois, Y. *J. Phys. Radium*, **3**, p. 320 (1932).

A two co-ordinate light pointer and its application to a recording interferometer

By H. G. Kuhn and H. J. Lucas-Tooth, Clarendon Laboratory, Oxford

[*Paper received* 15 *April*, 1958]

A light pointer is described which allows the deflexions of two mirrors to be recorded in a two co-ordinate graph. This is used in a direct-recording Fabry–Perot interferometer for displaying the intensity as a function of air pressure.

Vhen the dependence of one physical quantity on another ne is to be recorded, one normally allows one of them to ary at a constant rate and records the other against a time ase. In pen recording and in photographic recording with light pointer, one co-ordinate is usually provided by the otation of a drum which does not lend itself readily to anyhing but a uniform motion, and therefore serves as time base.

The following section describes a form of light pointer vhich allows the rotations of two small mirrors, such as alvanometer mirrors, to produce a photographic plot of one gainst the other, independently of their rate of change. The evice is so simple that it may have been described before, ut it is certainly not well known. In any case it has not een applied before to interferometric recording for which it ffers special advantages; this application will be described in he further sections. A preliminary report on this work has een published in the Proceedings of the Bellevue Conference n Interferometric Spectroscopy.$^{(1)}$

THE LIGHT POINTER

Two small mirrors, the rotations of which are to be recorded, are shown as M_0 and M_1 in Fig. 1. Mirror M_0 rotates about a vertical and mirror M_1 about a horizontal axis; if, in fact, the second mirror also turns about a vertical, or about any other axis, a suitably oriented plane mirror can be used for changing the rotation into the desired direction. First consider a single ray leaving the point source S_0 and impinging on M_0; mirrors M_0 and M_1 are placed in conjugate points on the axis of a large lens L_2, so that the ray leaving M_0 is made to pass through M_1, regardless of its direction. After reflexion from M_1, the ray is incident on the photographic paper which is bent into a cylindrical shape as shown. Rotations of M_0 and M_1 will then produce movements of the light spot in directions perpendicular and parallel to the length of the paper which may be called the y- and x-directions.

In actual fact, since one has to deal with pencils of rays

(Fig. 2), a lens L_1 is inserted in order to collimate the light in the usual way, and a further lens L_3 forms an image of the point source on the photographic paper. Strictly speaking, M_0 and M_1 are to be placed in conjugate points not of L_2 but of the system consisting of L_2 and L_3, but L_3 is so close to M_1 that it has little influence on the position of the second conjugate point; S_2 is the image of S_0 formed by L_1, L_2 and L_3.

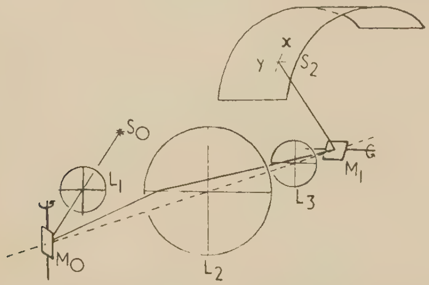


Fig. 1. Diagram of two co-ordinate light pointer

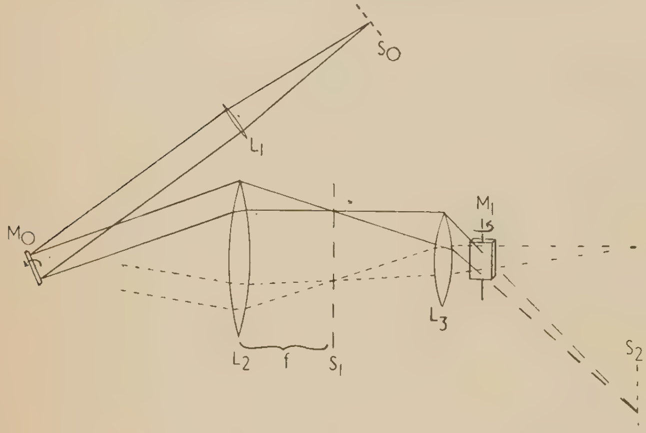


Fig. 2. Focusing in two co-ordinate light pointer

The dotted lines in Fig. 2 show the rays after rotation of M_0; it is seen that the positions of S_1 and S_2 are displaced, but that the rays always pass through M_1. There are no lenses between M_1 and the paper; the *x*-deflexion is therefore accurately proportional to the rotation of M_1, provided the axis of rotation of the latter lies in the plane of M_1 and coincides with the axis of curvature of the photographic paper. The rotation of M_1 need not be confined to small angles.

The only optical component of which high performance is required is L_2; it has to be reasonably free from curvature and distortion in the focal plane, for a field of about 5° from the axis. A camera lens of focal length 20 cm and aperture $f/2{\cdot}9$ was used in the authors' experiments; L_1 and L_3 were small lenses of focal length 15 and 12·5 cm respectively. The mirror M_0, of width 1 mm, was that of a Flik galvanometer (by Cambridge Instrument Co.), and M_1 was a rectangular mirror 7 × 15 mm. The photographic paper was pressed against a sheet of Perspex which was bent into a curvature of radius 40 cm. Deflexions up to 7 and 45 cm respectively in the *y*- and *x*-directions were used. The point source S_0 was a Sylvania zirconium arc (2 W) (by Standard Telephones and Cables Ltd.) the light spot of which had a diameter of 0·08 mm.

THE RECORDING INTERFEROMETER

In interferometric spectroscopy, photoelectric recording has often great advantages compared with photography. In a method first developed by Jacquinot and his co-workers,(and now widely used, the optical path in the Fabry–Pero etalon is varied at an accurately constant rate by control o the air pressure, and the intensity in the centre of the rin system is recorded by means of a photomultiplier and commercial pen-recorder. The accuracy of the wave numbe scale depends on the degree to which the rate of change o the air pressure can be kept constant, and it has prove difficult to achieve the accuracy required for some purposes.

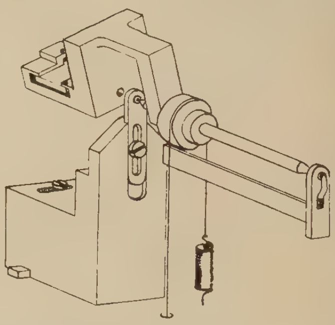
In the present method, the signal, i.e. the intensity, i recorded directly as a function of the air pressure, which i changed at an arbitrary rate, without any pretence a linearity. This is done by means of the light pointer jus described and a specially designed manometer causing th rotation of a mirror accurately proportional to the chang in pressure.

THE BELLOWS MANOMETER

The manometer consists of a cylindrical metal bellow closed at one end; the bottom end is soldered to a base plate A tube passing through the latter connects the inside of th bellows with the etalon chamber. A phosphor-bronze tap attached to the top of the bellows passes over a drum whic is free to rotate about its horizontal axis and carries a mirror The free end of the tape is held taut by a helical spring.

Fig. 3 shows the tape and drum assembly of the mano meter; the bellows is below the diagram. In order to ensur that the axis of rotation passes through the reflecting surface a hole is drilled completely through the cranked mirro mount. The front surface of the aluminium-coated mirror i pressed against three screws which are adjusted so that t surface passes through the axis of the hole. The axle is finally inserted and clamped as shown and pivoted between the jewel bearings.

Fig. 3. Mirror assembly of manometer



In the authors' instrument, a pressure change of 1 cm of mercury caused an extension of the bellows of 0·2 mm and with a drum of diameter 4 mm, a deflexion of 8 cm. In fact the drum consisted of three portions of different diameters, so that the range of the instrument could be changed. For the same reason, two bellows were used, soldered end-to-end, and a clamping arrangement allowed either one or both to be in operation.

The volume of air inside the bellows was kept small by means of a solid metal cylinder which occupied most of the space. The outside was encased and could, if necessary, be connected to an air container; the effects of change of barometric pressure during a recording could thus be easily eliminated. The time of response of the manometer depends on the mechanical properties, on the inside volume and its rate of change with pressure and on the dimensions of the connecting tubes. In fact, the response was found to be very rapid, of the order of one-tenth of a second, and no special attention had to be paid to this feature.

PERFORMANCE TESTS

The final tests were carried out on the complete instrument, hen it had been connected to an etalon and photomultiplier, ith d.c. amplification. The usefulness of the method depends ainly on the following conditions: (i) absence of hysteresis the pressure scale; (ii) linearity of the pressure scale; and i) linearity of the intensity scale.

(i) The full range of pressure difference was applied to the anometer repeatedly and at varying speeds. Every time ie pressure returned to atmospheric the position of the ght pointer was marked photographically, by the application an electric signal at constant pressure. No trace of ysteresis was found.

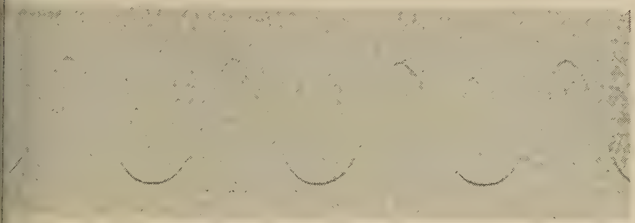


Fig. 4. Linearity test with the line 5460 Å of Hg^{198}

(ii) The linearity of the pressure scale was tested inter- erometrically. Recordings were made with the mercury nes 5460 Å and 4358 Å from a discharge tube containing ie pure isotope 198. With an etalon of spacing 4 cm and the se of the 12 mm drum, as many as nine and twelve orders vere scanned respectively; both bellows were used and the otal change in pressure was 20 cm of mercury. The distances etween successive peaks were measured, and under these xtreme conditions a slight deviation from linearity was just etectable. Fig. 4 shows a portion of one of these records. f the displacement x is expressed as function of the pressure p,

$$x = \alpha p(1 + \beta p),$$

nd the constant β is found to be smaller than 0·0005 per cm f mercury.

For most practical purposes the deviations from linearity vill thus be negligible if the type of bellows and size of drum re suitably chosen. If necessary, a small correction could asily be applied.

(iii) The linearity of the intensity scale was tested by passing currents of known ratio through the galvanometer. If the deflexion is expressed as function of the current i and its value i_0 for full deflexion by

$$y = \alpha i/i_0(1 + \beta i/i_0)$$

the value of β is certainly smaller than 0·03.

As a working test of the system the hyperfine structure of the line 6250 Å of La($5d^26s\,{}^4F_{9/2} - 5d^26p\,{}^4G_{11/2}$) was recorded (Fig. 5). The line was excited in a hollow cathode tube cooled with liquid air, and an etalon of spacing 0·75 cm was used. The recording lasted five minutes. The components were measured and the results were in perfect agreement with the measurements by Lührs.$^{(3)}$ The dotted appearance of the tracing is due to the zirconium arc which had developed a fault leading to flicker.

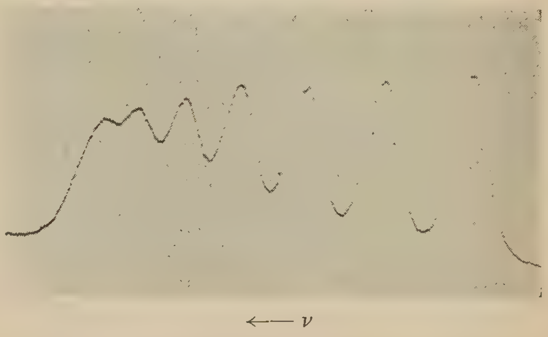


Fig. 5. Hyperfine structure of La line 6250 Å

For accurate measurements it is advisable to produce a grid system of reference lines photographically before the recording is made; this avoids effects due to shrinkage of the paper.

REFERENCES

(1) Kuhn, H. G., and Lucas-Tooth, H. J. *J. Phys. Rad.*, **19**, p. 293 (1958).
(2) Jacquinot, P., and Dufour, Ch. *J. Rech. Cent. Nat. Rech. Sci.* (6), p. 91 (1949).
(3) Lührs, G. *Z. Phys.*, **141**, p. 486 (1955).

A rotational viscometer employing a reference liquid

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[*Paper first received* 5 *May, and in final form* 11 *June*, 1958]

The viscometer described is a rotational one in which a free rotor is accelerated by the torque transmitted through a reference liquid by a driven rotor, and retarded by the torque acting through the liquid under test which is restrained by a stator. The free rotor thus attains an equilibrium speed of rotation. The ratio of the rates of rotation of the driven and free rotors is a linear function of the viscosity being measured, and, apart from a negligible effect of bearing friction, is independent of the absolute rotational speed of the driven rotor when using Newtonian liquids.

The theory of the viscometer is given together with an account of an experimental verification. A discussion of the practical application of the instrument includes a study of the accuracy obtainable, and it is shown that with one instrument a viscosity range of 1000 : 1 may be obtained for which the maximum error does not exceed approximately ±0·5% of the measured viscosity for a single test. For error limits of ±0·2% the range is 30 : 1.

A feature of the viscometer is that it readily lends itself to the provision of a simple digital "read-out" in any required units.

xperience in a refinery with various types of continuous ecording viscometers showed the need for a more accurate nd reliable instrument, and suggested that a successful plant iscometer would: (*a*) be a rotational type with comparatively wide clearances so that it could deal with samples contaminated with solid particles; (*b*) have an indication that was independent of mains frequency by a method that was not unduly elaborate; and (*c*) be able to work with the sample under pressure so that the liquid being tested could be disposed of readily.

A simple way of achieving independence of the mains frequency with a rotational viscometer is to use a reference liquid of known viscosity and measure the ratio of the viscosities of the test and reference liquids.

A "double Couette" viscometer using a reference liquid was designed by Pryce-Jones* for the observation of small differences in viscosity. This instrument had two rotating cups and so would be difficult to adapt for use with a flowing sample. Further, it employed the principle of bringing a body to rest in order to establish the equivalence of two torques, and this would entail difficulties with the static friction of bearings in a plant instrument.

In the viscometer† described below, the rotational speed of a free rotor varies automatically to maintain two opposing torques in equilibrium, and the viscosity ratio is found by measuring a speed ratio. The theory of the instrument is given together with an account of an experimental verification. This is followed by a discussion of the practical application of the instrument, including the accuracy and range obtainable.

THEORY

One form of the viscometer is illustrated diagrammatically in Fig. 1 to show the principle of the instrument. The cups and bobs are coaxial; the upper bob being rotated by the motor, and the lower one by the upper cup which is free to rotate. The lower cup is fixed.

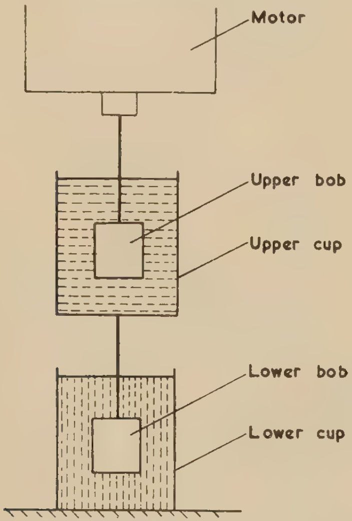

Fig. 1. The principle of the viscometer

When the upper bob rotates at a constant speed, an accelerating torque acts on the upper cup, which, being free, rotates too. Its motion is, however, opposed by the retarding torque that acts on the lower bob. As the upper cup and lower bob are joined rigidly together, there is no loss of torque between them. When they have attained an equilibrium speed of rotation, the accelerating and retarding torques are equal. Neglecting bearing friction, this can be expressed by the following equation,

$$k_r\eta_r(\omega_r - \omega_s) = k_s\eta_s\omega_s \qquad (1)$$

where k_r and k_s are geometrical constants of the upper and lower cup and bob systems respectively; η_r and η_s are the viscosities of the liquids in the upper and lower cups; and ω_r and ω_s are the angular velocities of the upper and lower bobs.

In general there will be a bearing between the upper bob and cup, the friction of which will contribute to the accelerating torque. The bearings which support the upper cup and lower bob will increase the retarding torque.

Let it be assumed that a torque T required to turn a bearing at an angular velocity ω is given by

$$T = a\omega + b \qquad (2)$$

where a and b are constants; a is proportional to the coefficient of "viscous friction," and b is the "Coulomb friction" torque. The torque required to overcome the static friction of the bearings is of no account, except when starting the apparatus from rest.

Taking account of these frictional torques, and following the notation used above, equation (1) becomes

$$(k_r\eta_r + a_r)(\omega_r - \omega_s) + b_r = (k_s\eta_s + a_s)\omega_s + b_s \qquad (3)$$

and solving for ω_r/ω_s gives

$$\frac{\omega_r}{\omega_s} = \left[\frac{k_s}{k_r\eta_r + a_r}\right]\eta_s + \left[1 + \frac{a_s}{k_r\eta_r + a_r} + \frac{(b_s - b_r)}{(k_r\eta_r + a_r)\omega_s}\right] \qquad (4)$$

This shows that if a reference liquid of known viscosity η_r is put into the upper cup, the ratio of the speeds of the two bobs ω_r/ω_s is a linear function of the viscosity η_s of a sample placed in the lower cup, so long as the term $(b_s - b_r)/(k_r\eta_r + a_r)\omega_s$ is negligible. This will be true if the torque transmitted through the reference liquid is large compared with the "Coulomb friction" torques of the bearings. Thus by measuring the ratio ω_r/ω_s, η_s may be determined; and this determination is made without measuring a torque directly.

EXPERIMENT

The feasibility of making a viscometer employing a reference liquid and a free rotor has been proved experimentally. It has been demonstrated that ω_r/ω_s is a linear function of η_s, and that it can readily be made independent of ω_r.

The apparatus used is shown in Fig. 2. It was a simple practical version of that given diagrammatically in Fig. 1, and had disks instead of cylindrical bobs. The instrument was housed in a cabinet thermostatically controlled at 30° C. The liquids used were type M.S. 200 fluids (by Midland Silicones Ltd.). These were chosen for their stability, and because their small temperature coefficient of viscosity made it unnecessary to control the temperature closely.

The first experiment was designed to find the effect of the speed-dependent term in equation (4) arising from the Coulomb friction torque of the bearings. As there was no bearing between the upper bob and cup, $a_r = b_r = 0$ in equation (4), which becomes after re-arrangement

$$\omega_r = \left(\frac{k_s\eta_s + a_s}{k_r\eta_r} + 1\right)\omega_s + \frac{b_s}{k_r\eta_r} \qquad (5)$$

In the experiment k_r, k_s, η_r and η_s were kept constant, and corresponding values of ω_r and ω_s were measured.

Liquids of similar viscosity (of the order of 100 P) were put into each cup, and the rates of rotation were measured with a stop watch. This was done for various motor speeds between about 0·8 and 2·4 rev/s.

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* Pryce-Jones, J. *J. Sci. Instrum.*, **18**, p. 39 (1941).

† British Patent Application No. 24561:57 (2 August, 1957).

A graph showing upper bob speed plotted against lower ob speed is given in Fig. 3. The relationship is linear, and e line passes through the origin, showing that in equation (5) is a constant and that the term $b_s/k_r\eta_r$ is negligible.

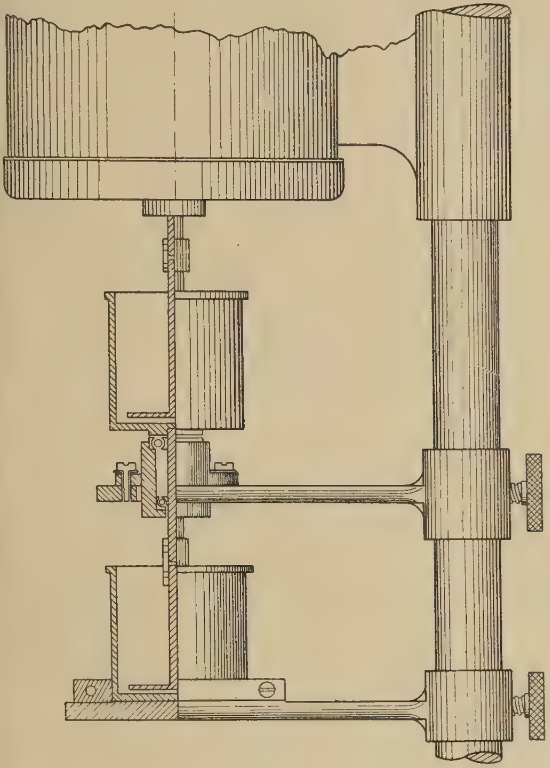

Fig. 2. The experimental apparatus

Dimensions of the experimental apparatus (*in.*)

Cup diameters	1·820
Cup depths	2·0
Cup filling depths	1·5 (not critical)
Upper disk diameter	1·4748
Lower disk diameter	1·4755
Upper disk/cup gap	0·078 approximate (left set up)
Lower disk/cup gap	0·078 (jig used to ensure constancy)

Equation (2) is therefore valid and the last term in equation (4) may be omitted, if $k_r\eta_r$ is sufficiently large, leaving

$$\frac{\omega_r}{\omega_s} = \left(\frac{k_s}{k_r\eta_r + a_r}\right)\eta_s + \left(1 + \frac{a_s}{k_r\eta_r + a_r}\right) \tag{6}$$

for the general case, and

$$\frac{\omega_r}{\omega_s} = \left(\frac{k_s}{k_r\eta_r}\right)\eta_s + \left(1 + \frac{a_s}{k_r\eta_r}\right) \tag{7}$$

for the experimental apparatus.

The remaining experimental work was a calibration of the apparatus, by measuring ω_r/ω_s for various values of η_s, in order to test equation (7). The reference liquid had a viscosity $\eta_r \simeq 100$ P, and was put into the upper cup. Samples having viscosities ranging from approximately 1 to 100 P were put into the lower cup in turn, and the ratio ω_r/ω_s was measured. The ratio was determined by counting the revolutions of the driven and free bobs during an arbitrary period of time, with the aid of Post Office counters operated by a contact on the motor shaft, and a capacitance pick-up on the free lower bob.

The first experiment having shown that variations of motor speed had no effect, the motor was run at about 1 rev/s, and no attempt was made to keep this speed constant. (There were, in fact, slow variations in the motor speed.) Counting was stopped when the free bob had completed some 400 revolutions. This was repeated a few times and the mean counts ratio for the sample was found.

The kinematic viscosities of the samples were measured with suspended level U-tube viscometers immersed in a

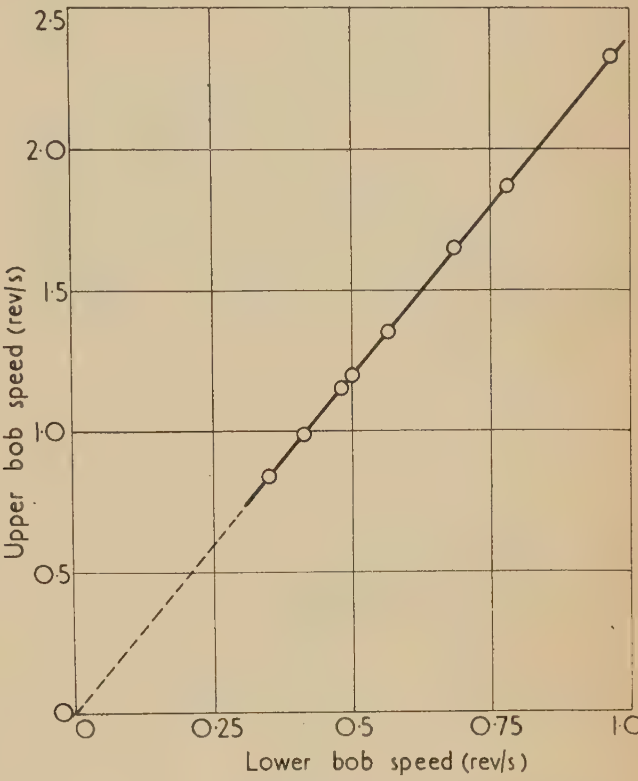

Fig. 3. Plot of upper against lower bob speed for constant viscosities

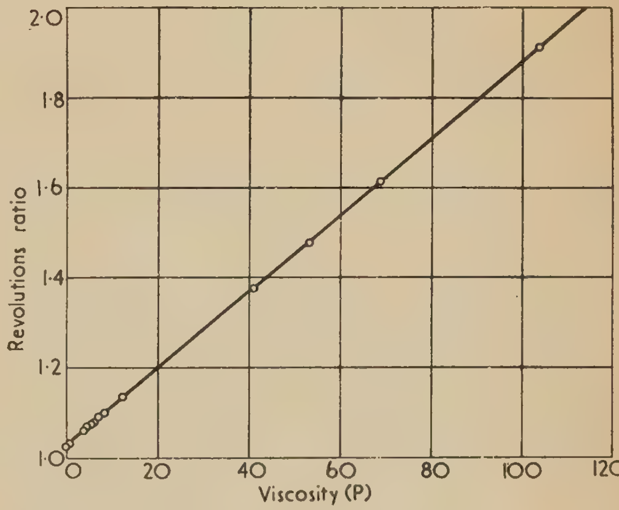

Fig. 4. Calibration of the revolutions ratio of the driven and free bobs against viscosity

thermostat bath maintained at 30° C. The mean of the results of a number of tests was taken, and the corresponding dynamic viscosity was obtained by multiplying the kinematic viscosity by the mean density of the liquids ($0\cdot964$ g/cm^3).

The results, which are plotted in Fig. 4, verify the linear relationship between ω_r/ω_s and η_s given in equation (7), which was the equation being tested.

DISCUSSION OF PRACTICAL APPLICATION

Cup and bob systems. A viscometer for use on a plant could follow the general design of the experimental apparatus and have the continuous sample flowing into the bottom of the lower fixed cup and overflowing from the top of it.

A more widely useful plant viscometer needs to be able to handle the flowing sample under pressure. A design which allows for this is illustrated diagrammatically in Fig. 5. The central bob is driven by the motor through a magnetic coupling. The free bob is a hollow closed cylinder which is both the cup for the reference liquid and the bob for the sample liquid.

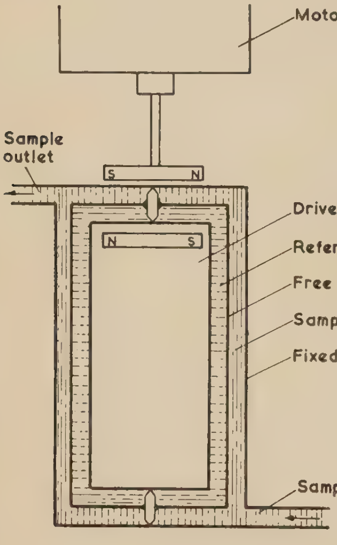

Fig. 5. Plant viscometer for handling a flowing sample under pressure

A laboratory viscometer, being used for measurements on batch samples, may have an open cup. A convenient arrangement would be an inversion of the experimental apparatus with the motor rotating the lower cup which would contain the reference liquid, the upper bob being fixed.

Counting procedure for digital "read-out" in required units. By a simple arrangement of counters the indication of the viscometer may be given digitally in any required units. This may be illustrated with the calibration of the experimental apparatus, which was

$$\eta_s = 118\cdot3n_r/n_s - 121\cdot6 \qquad (8)$$

where n_r/n_s is the revolution counts ratio. If the pulse signals from the free rotor are fed to a batch counter set to the number 1183, and the counts from the driven rotor, with the number 1216 subtracted, are stopped when the batch number is reached, then the indicated count will be numerically equal to ten times the viscosity.

If ageing of the reference liquid or wear in the bearings should occur, the constants set on the counters may be adjusted to allow for this. Recalibration is thus very simple and only two points are required, one of which may be found by using the "zero" viscosity of air.

ACCURACY

The errors caused by digital operation are the uncertainty of ±1 in the count for the pulses from the driven rotor, and the rounding-off errors of $\pm0\cdot5$ in the constants set on the counters (assuming that the batch counter for the free rotor starts as well as stops at the instant a pulse arrives). If the percentage error limits in the indicated viscosity are denoted by $\Delta\eta\%$, it can be shown that

$$\Delta\eta\% = \pm\left[\frac{1\cdot5(k_r\eta_r + a_r)}{\eta_s k_s} + 0\cdot5\right]\frac{100}{n_s} \qquad (9)$$

Viscosity ranges. The range depends on the accuracy required and the time available for a measurement. Equation (9) shows that if a certain maximum error is specified for the indication, then there is a minimum viscosity which may be measured with a particular apparatus and value of n_s.

The maximum viscosity that can be measured depends on the time that can be allowed for a measurement, which is the time required for the free rotor to transmit n_s pulses to the batch counter. If the driven rotor transmits fifty pulses a second, then it can be shown that to a close approximation the time t for a measurement is given by

$$t = \frac{n_s}{50}\left(\frac{k_s\eta_s}{k_r\eta_r + a_r} + 1\right) \qquad (10)$$

If the minimum viscosity is set by error limits of $\pm0\cdot2\%$ being specified, and the maximum viscosity by a maximum measuring time of about ten minutes, then equations (9) and (10) can be used to show that the viscosity range available is 30 : 1. If error limits of $\pm0\cdot55\%$ are acceptable, then the upper limit of the range can be extended by reducing n_s by a factor of ten. A total viscosity range of 1000 : 1 is then obtainable with one apparatus in two spans, the only adjustments required being changes in the constants set on the counters.

CONCLUSIONS

The viscometer described has features which make it particularly suited to the routine measurement of product quality. The instrument lends itself to robust construction because there are no torsion springs and the bearings turn continuously, thus eliminating static friction difficulties. A wide viscosity range is obtainable with one apparatus, and, so long as the thermostatic control of the viscometer proper is adequate, the accuracy of the indication for Newtonian liquids cannot be affected by variations in ambient temperature, mains frequency or voltage.

A method of correcting for the response time delays of measuring equipment

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The error due to the response time delay of measuring equipment on a given input waveform is obtained by considering the output response to a unit step input impulse and applying Laplace Transform analysis. Formulae are derived for correcting the error and applied to (*a*) resistance/capacitor decay curves; (*b*) the calculation of velocity constants in chemical reaction systems.

many types of experiment it is necessary to follow the e at which a given function varies with time. The ideal paratus would be one in which the detector element, plifier and recording system faithfully reproduce this ction. Unfortunately this is not always the case. A emical reaction, for example, could be measured by the e of output of heat, measured in terms of increase of mperature. The thermocouple or detecting element due its thermal capacity and heat conductivity, might easily roduce a significant time lag. If the thermocouple output measured and recorded by means of a galvanometer, the ertia and damping of this, as with any amplifying system, ould also introduce errors. Inevitably some time delay is troduced by the recording equipment.

This problem has been appreciated by a number of workers ut no general quantitative treatment has been published. enedicks(1) in 1910 used a conductivity method to study the te of combination of OH^- and H^+. The recording system onsisted of a string galvanometer and rotating drum camera. he response time of the galvanometer limited the speed of easurement to reactions taking longer than 0·04 s. The per included a mathematical and experimental investigation the limiting factors. The mathematical calculations were ade by formulating the differential equations of the galanometer movement and solving them for various contions. The galvanometer constants were determined by xperiment. Though somewhat laborious this method can e used where the constants of the differential equation are nown. Apart from this only a general remark by Chance(2) nd an arithmetical method for correcting the time delay y Hill(3) have been published.

The following is a more general analysis to assess the elative significance of this delay. It is assumed throughout hat all functions representing the recording equipment are athematically continuous and that the variations of such unctions with time are governed by linear differential quations. To avoid too much mathematical manipulation he Laplace Transform theory has been used.

RESPONSE TIME EFFECTS OF AMPLIFIER AND RECORDER

In several cases the detecting element introduces no ignificant time lag and the response time of the equipment is etermined by the amplifier and recorder. An example of his is the use of an emissive type photoelectric cell, as the etecting element, where changes can normally be followed up to 10^{-5} s. The direct time lag of the system can be etermined by injecting into the amplifier a unit step input, .e. instantly change the applied voltage V by an increment dV to $V + dV$. In the majority of cases, the resulting output s of the form $(1 - \varepsilon^{-\beta t})$, as in Fig. 1. Other types of output can be obtained, as indicated in a further section below, but in general they can be analysed as a series of exponential terms and the resulting conclusions are the same.

The Laplace Transform of the input step pulse is $1/p$, and that of the output waveform, $(1 - \varepsilon^{-\beta t})$ is $\beta/p(\beta + p)$. Where "β" is a constant and "p" the differential d/dt. This means the amplifier is equivalent to a network represented by the transform $\beta/(p + \beta)$. Using this equivalent network transform we can now determine the output waveform to an input of $(1 - \varepsilon^{-\alpha t})$ as follows:

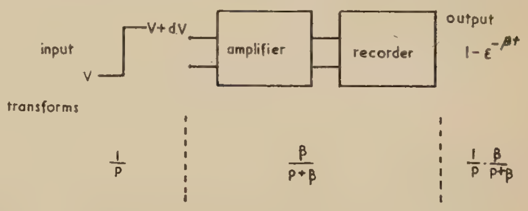

Fig. 1. Schematic representation of Laplace Transform analysis

(1) Input waveform $f(t) = (1 - \varepsilon^{-\alpha t})$ where α is a constant.

(2) Laplace Transform of input

$$\left[F(t) = \int_0^\infty f(t)\varepsilon^{-pt}\,dt\right] = \frac{\alpha}{p(p+\alpha)}$$

(3) Network transform

$$\text{(from above)} = \beta/(\beta + p)$$

(4) Laplace Transform of output

$$[F(t) \times \text{network transform}] = \frac{\alpha}{p(p+\alpha)} \times \frac{\beta}{(\beta + p)}$$

(5) Output waveform

[Inversion of the Laplace Transform (4)]

$$Y = 1 - \frac{\beta}{\beta - \alpha}\varepsilon^{-\alpha t} + \frac{\alpha}{\beta - \alpha}\varepsilon^{-\beta t} \qquad (1)$$

From this it can be seen that if the output waveform is to faithfully copy the input, β must be much greater than α. Fig. 2 shows the relative distortion introduced when $\beta = 10\,\alpha$. The process can be similarly repeated for different types of input waveforms with the same general results. The theory can be used to correct for the distortion introduced when β is only slightly greater than α. By accurately determining the output waveform, of the unknown input, then converting to the appropriate Laplace Transform and dividing by the network transform, the Laplace Transform of the input waveform is obtained. The true input waveform can then be derived from this.

A less accurate, though in many ways more convenient, form of correction can be obtained by measuring the slope of the output curve. The correction factor can be derived as follows. Differentiating the output waveform we obtain:

$$\frac{dY}{dt} = \frac{\beta\alpha}{\beta - \alpha}\varepsilon^{-\alpha t} - \frac{\beta\alpha}{\beta - \alpha}\varepsilon^{-\beta t} \tag{2}$$

and when $Y = 1 - \gamma$ where $0 < \gamma < 1$ then from (1)

$$\frac{\beta}{\beta - \alpha}\varepsilon^{-\alpha t'} = \frac{\alpha}{\beta - \alpha}\varepsilon^{-\beta t'} + \gamma \tag{3}$$

where t' is the time taken to decay to $(1 - \gamma)$. The slope at t' can then be derived by substituting equation (3) in (2),

$$\left(\frac{dY}{dt}\right)_\gamma = \alpha\left(\frac{\alpha}{\beta - \alpha}\varepsilon^{-\beta t'} + \gamma\right) - \frac{\alpha\beta}{\beta - \alpha}\varepsilon^{-\beta t'}$$
$$= \alpha\gamma + \alpha\left(\frac{\alpha}{\beta - \alpha}\varepsilon^{-\beta t'} - \frac{\beta}{\beta - \alpha}\varepsilon^{-\beta t'}\right)$$
$$= \alpha\gamma - \alpha\varepsilon^{-\beta t'}$$

we can thus determine α from:

$$\alpha = \left(\frac{dY}{dt}\right)_\gamma \Big/ (\gamma - \varepsilon^{-\beta t'}) \tag{4}$$

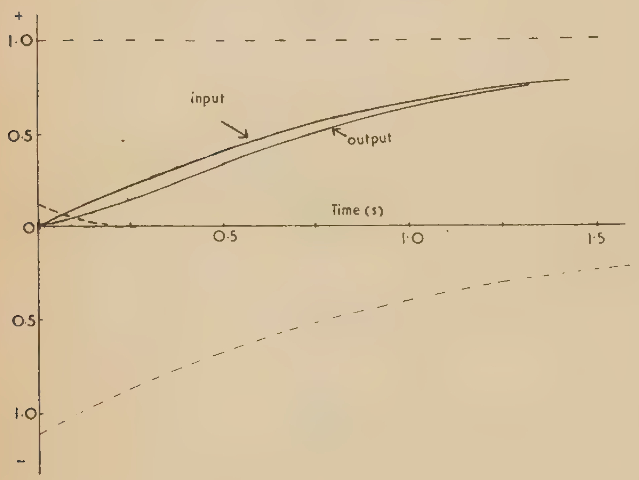

Fig. 2. Input $(1 - \epsilon^{-\alpha t})$/output $\left(1 - \frac{10}{9}\epsilon^{-\alpha t} + \frac{1}{9}\epsilon^{-10\alpha t}\right)$ curves, when $\beta = 10\alpha$

The error involved is more easily appreciated by comparing the above result with one obtained by a similar analysis on the undistorted input waveform viz.:

$$\alpha = \left(\frac{dY}{dt}\right)'_\gamma \Big/ \gamma \tag{5}$$

where $\left(\frac{dY}{dt}\right)'_\gamma$ is the slope of the undistorted input waveform at the point $(1 - \gamma)$.

The true decay constant "α" can thus be determined from the output curve by measuring the slope at some fixed point, usually when the amplitude has fallen by half (i.e. $\gamma = \frac{1}{2}$), and the corresponding time from initiation t'. The value of β having previously been determined from the response to a unit step pulse input.

In most cases the problem is basically that of obtaining numerical values of β and α, for the types of waveform considered previously. Although it has been stated that β is obtained experimentally by applying a unit step impulse to the system, this measurement is not essential. Both β and α can be obtained from the output curve (1) by substituting in equation (4) the appropriate values of the measured slope $(dY/dt)_\gamma$ at various values of t' and γ. Several equations can then be formed from which the tw unknowns, α and β, can be accurately determined. In th way, the analysis can be applied to systems where it impossible to apply an instantaneous decremental change such as the measurement of change of heat by a thermo couple, at the input.

Occasionally the response of the detector, amplifier an recorder is not logarithmic to a unit step impulse. Th would be made apparent, if the method of the previou paragraph was applied, by variation of the calculated value of α and β with different values of t'. A general analysis ca be made, however, in the same way as equation (1) wa derived. The form of the new network transform bein obtained experimentally by applying a unit step input. more convenient method, which again disposes of this latte measurement, is to limit observation of the slope of th output curve to a fixed time after initiation. Over a sma interval of time about this point the network response ca be regarded as logarithmic, with an equivalent decay constan β', so equation (4) can be applied. A second equatio relating α and β' can be obtained by altering some fac which affects the rate of decay of the input waveform. Th could be achieved, for instance, by changing the capaci value in a resistance-capacitor network or the concentratio of one of the reactants in a chemical reaction. The ne slope of the output curve, at the same time after initiatio can be substituted in equation (4) to provide a secon equation and the values of α and β' determined.

The preceding treatment has dealt with the effects due t the time lag of the amplifier and recorder. It is also possib that the measuring element could introduce a similar tim lag and the case of a thermocouple was cited. In princip the analysis of this is exactly the same as above, the respons of the element being obtained to a step pulse input, and th equivalent network transform calculated. Avoidance an correction of errors can be similarly made.

APPLICATIONS

(1) *Resistance-capacitor decay curves.* The limitations an corrections suggested by the previous theory were firs checked by making measurements on the rate a series o

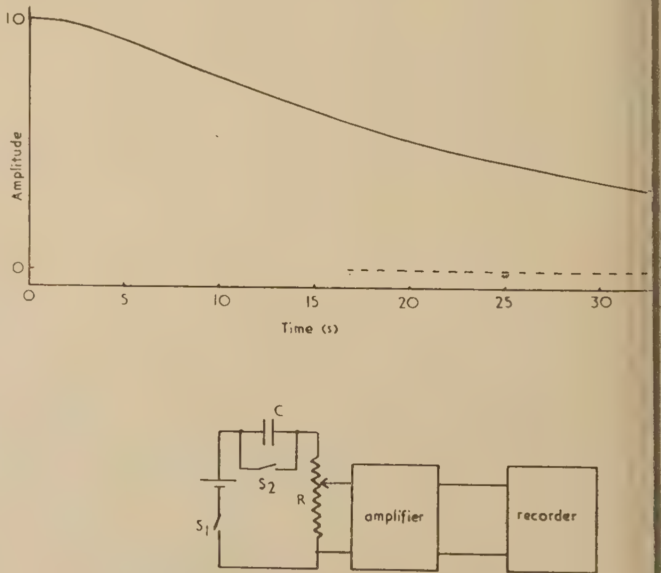

Fig. 3. Resistance-capacitor decay curve and circuit $C = 8\ \mu\text{F}$; $R = 2{\cdot}81\ \text{M}\Omega$; $\beta = 0{\cdot}155$.

acitors were charged through a high resistance. Observa- ns were made with an amplifier and pen recorder. A ical circuit and curve obtained in this way is shown in . 3. The capacitor C is first short circuited by switch S_2. closing switch S_1, a step input is applied to the amplifier the response curve recorded. When the current has ched its maximum value the switch S_2 is opened again the rate at which the capacitor charges recorded.

The curve shown is the rate a 8 μF capacitor is charged ough a 2·81 MΩ resistor. The component values were asured independently. The resistance was then calculated m the slope of the curve as follows:

When $\gamma = 0{\cdot}5$ the slope measured $0{\cdot}0206\ \mathrm{s}^{-1}$. With no rrection we can calculate R from

$$\alpha_1 = \text{slope}/\gamma = 0{\cdot}0412$$

ith $C = 8\ \mu\text{F}$

$$R = 1/\alpha_1 C = 3{\cdot}03\ \text{M}\Omega$$

ing the previous correction

$$\alpha_2 = \text{slope}/(\gamma - \varepsilon^{-\beta t'})$$

asurements gave $\beta = 0{\cdot}155$ and $t' = 21{\cdot}56$ s

en
$$\alpha_2 = 0{\cdot}0444$$
$$R = 1/C\alpha_2 = 2{\cdot}81\ \text{M}\Omega$$

series of such measurements is given in Table 1.

Table 1. *Comparison of uncorrected and corrected CR values with relative variation of recorder delay*

apaci-tance (μF)	*R un-corrected* (MΩ)	*R corrected* (MΩ)	β	*K*	γ
1	4·34	2·44	0·253	3·53	0·18
2	3·59	2·81	0·253	4·80	0·369
4	3·30	2·73	0·253	7·60	0·589
6	3·21	2·90	0·155	10·60	0·25
8	3·03	2·81	0·155	12·35	0·50
10	2·90	2·81	0·155	16·70	0·50
12	2·85	2·80	0·155	19·90	0·50

here K = half-time CR decay/half-time amp. decay

The figures show general agreement with the theory. It interesting to notice that a discrepancy of some 1·5% ccurs even when the ratio of the half times is approximately venty.

(2) *Correction of chemical velocity constants.* The preced- g analysis can be applied in a similar way to many types f waveform. The particular application for which it was eveloped is the correction of errors introduced by the easuring equipment in the study of fast chemical reactions y the stopped flow systems of Roughton$^{(4)}$ and Chance.$^{(5)}$ he correction for different orders of chemical reaction can e derived as follows:

(*a*) First order reaction. The rate at which a molecule B dissociates into two independent units A and B can be epresented by

$$\frac{dx}{dt} = k(a - x) \tag{6}$$

here $(a - x)$ is the concentration of AB at time t, "a" its itial value, and k is termed the velocity constant. Upon tegrating this we obtain

$$x = a(1 - \varepsilon^{-kt}) \tag{7}$$

The detector element is chosen to follow the change of x with time, and using equation (7), we can then calculate k. When the measuring equipment has introduced a delay error into the record however, the constant k obtained will be lower than its true value, as indicated by equation (1). If the velocity constant is calculated by an equation such as (5), with no correction, then by comparison with (4) the true velocity constant, taken as the value at $\gamma = \frac{1}{2}$, is given by

$$\text{True } k' = \text{Observed } k/2(\tfrac{1}{2} - \varepsilon^{-\beta t'}) \tag{10}$$

where t' is the time for the reactant AB to have fallen to half its initial value.

(*b*) Second order reaction. The manner in which a given component changes with time in a second order reaction can be calculated in a similar manner to that of equations (6) and (7). The function obtained, however, is cumbersome to deal with and though a similar analysis can be made to obtain a correction factor, the use of equation (10) is sufficiently accurate to a first order of magnitude.

Another simple and approximate form of correction can be obtained by considering the concentrations of the two reactants A and B as constant over the initial part of the curve so that

$$dx/dt = k[A]\,[B] \tag{11}$$

where x is the concentration of the product $[AB]$ at time t. The Laplace Transform of a function of this type is $1/p^2$, and applying an analysis to this in the same way as that

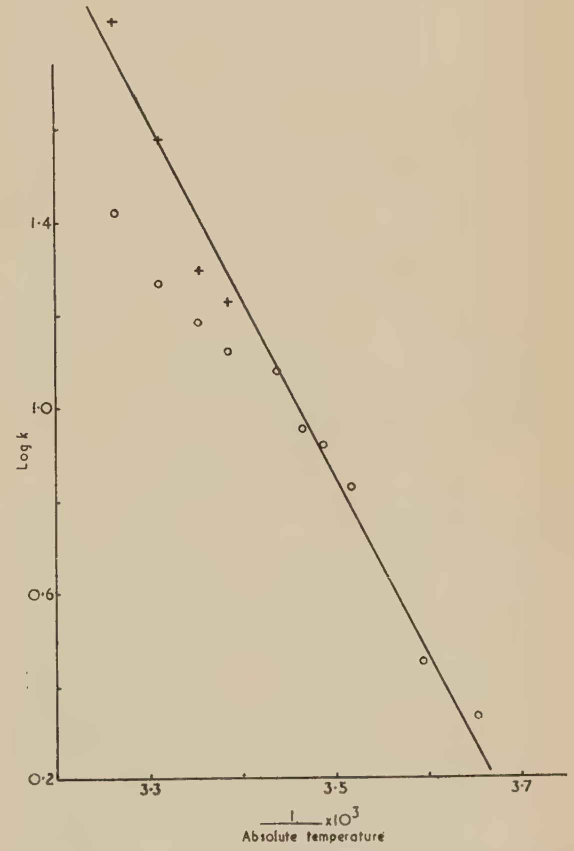

Fig. 4. The effect of response time delays on measured chemical velocity constants at various temperatures compared with corrected values

○ uncorrected. + corrected.

used for the exponential function earlier, we obtain the output curve as

$$Y = k[A][B]\left[t - \frac{1}{\beta}(1 - \varepsilon^{-\beta t})\right] \qquad (12)$$

By comparing the initial slopes we obtain

$$\text{True } k' = \frac{(\text{observed } k)t_1}{\left[t_1 - \frac{1}{\beta}(1 - \varepsilon^{-\beta t_1})\right]} \qquad (13)$$

where t_1 is the time the curve is linear over its initial portion.

(*c*) Dehydration of carbonic acid. The rate at which hydrogen ions disappear after hydrochloric acid is rapidly mixed with sodium bicarbonate has been formulated to a first approximation, by Brinkman, Margaria and Roughton,(6) as

$$kt = 2{\cdot}3 \text{ (pH value)} \qquad (14)$$

A series of observations were made by the author,(7) using a glass electrode to follow the rapid pH changes and determine the velocity constant k at different temperatures. At the higher temperatures, as can be seen in Fig. 4, the values obtained were reduced by the response time delay of the chopper-type amplifier used. The corrected values, using equations (10) and (13), are in good agreement with the expected values obtained by extrapolation of the true constants at lower temperatures, and the values measured by Dalziel(8) with an independent photoelectric technique.

REFERENCES

(1) Benedicks, C. *Z. Phys. Chem.*, **70**, p. 12 (1910).
(2) Chance, B. *Rev. Sci. Instrum.*, **22**, pp. 619, 627 (1951).
(3) Hill, A. V. *J. Sci. Instrum.*, **26**, p. 56 (1949).
(4) Roughton, F. J. W. *Proc. Roy. Soc.*, *B*, **115**, p. 47 (1934).
(5) Chance, B. *J. Frank. Inst.*, **229**, pp. 455, 613, 737 (1940).
(6) Brinkman, R., Margaria, R., and Roughton, F. J. W. *Trans Roy. Soc.*, *A*, **232**, p. 65 (1933).
(7) Sirs, J. A. *Trans Faraday Soc.*, **54**, p. 207 (1958).
(8) Dalziel, K. *Biochem. J.*, **55**, p. 79 (1953).

Laboratory and workshop notes

The use of argon at atmospheric pressure as Geiger counting gas in a windowless counter

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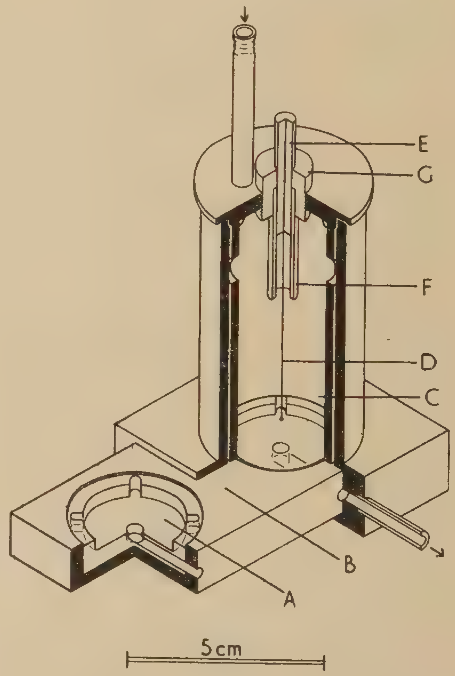
Helium at atmospheric pressure containing a small percentage of an organic quenching vapour is generally used in windowless flow counters operating in the Geiger region. However, in the U.K., helium is very expensive and considerable expense is incurred when using a flow counter continuously. Argon, which is about one-twentieth the cost of helium, containing a small percentage of ethanol vapour is used in the windowless counter to be described and although the Geiger plateau occurs at 1950 to 2250 V, i.e. at considerably higher voltages than with helium, laboratories dealing with radioactive materials usually possess power units capable of producing stabilized supplies of this magnitude.

The construction of the counter, which can be made almost wholly of brass, is shown in the figure. Samples mounted in aluminium planchettes are placed in Perspex holders *A* in the slide *B*. They are then presented to the counter in turn, the slide being held in position by a spring-loaded ball (not shown in the figure) which engages in an indentation drilled in the side of the slide. The indentations are accurately positioned so that each sample is held under the counter with the same geometry. The cathode *C* is nickel-plated internally and given a high polish. Copper was first used as cathode material but easily combined with radioactive hydrogen sulphide evolved by samples of methionine ^{35}S which were introduced into the counter. The anode wire *D* is made from 42 s.w.g. tungsten wire (by Johnson, Matthey and Co. Ltd.) and is held in a hole drilled along the length of a piece of 8 B.A. studding *E* by soft solder. A bead of glass 1 mm in diameter covers the lower end of the wire and a glass tube *F*, internally coated with Aquadag colloidal graphite (by Acheson Colloids Ltd.) which is brought into electrical contact with the anode, restricts the field at the top of the counter. The 8 B.A. studding is screwed into a piece of Perspex rod *G* which in turn is screwed into the top of the counter. The anode wire terminates about 5 mm above the sample. In general, the precautions detailed by Korff* were observed in building and operating the counter.

The argon required for the counter is obtained from a cylinder (by British Oxygen Gases Ltd.) and, after being passed through a drying tube and a flow meter, is passed through a bubbler having a coarse sintered tip and containing a depth of at least six inches of absolute ethanol kept at 20° C.



Windowless counter used with argon

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* Korff, S. A. *Electron and Nuclear Counters. Theory and Use.* 1st Ed., pp. 119–35 (New York: D. van Nostrand Co. Inc., 1946).

e resulting argon/ethanol mixture is then fed into the unter at the top and leaves through holes drilled in the rspex sample holders. A simple bubbler containing about inch of liquid paraffin is placed in the exit line to ensure at a slight positive pressure of argon is present in the unter to prevent the ingress of air. A flow of gas of cm^3/min is required for continuous operation and a gher gas flow rate is used when first using the counter to sh the air out rapidly. After changing samples two or ree minutes purging at the normal flow rate is sufficient remove any traces of air introduced.

When operated with the usual electronic scaling equipment e counter gave a Geiger plateau extending from 1950 to 50 V with a slope of less than 3% per 100 V. At an erating potential of 2080 V a background of 14 counts/min as recorded behind 3 cm of lead. Samples containing ^{14}C unted in the windowless counter gave 2·5 to 3 times the unt obtained with a thin end-window counter, window ickness 2·3 mg/cm^2, the sample being held about 2 mm om the window.

Acknowledgement is made to Mr. F. W. R. Penney who nstructed the counter and to Mr. F. P. Errington for the awing of the counter.

Metallic contacts to germanium and silicon

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is the purpose of this note to describe a reliable, simple ethod for the preparation of metallic contacts to the semionductors germanium and silicon. The contacts have high echanical strength and reasonable electrical properties, hile their shape is readily controlled; they have been found seful in various experimental applications.

The semiconductor sample is ground on a flat, glass surface ith an aqueous suspension of Alundum powder (particles f 15 μ diameter), and areas which are not to be covered by he contact are masked by painting with a dilute solution of olystyrene in toluene (10 g in 100 ml), which is allowed to lry. Silicon samples are then immersed for one or two ninutes at room temperature (10–30° C) in a "plating" olution consisting of 100 ml of saturated aqueous solution f copper sulphate, to which has been added 4 ml of 40% ydrofluoric acid; longer periods of immersion are required or germanium. It will be found that the unmasked region s coated with a deposit of copper. (If less sharply defined egions are required it is only necessary to "paint" the lating solution on the sample.)

After washing, the copper-plated region may be tinned with lead–tin solder (eutectic composition), using an aqueous solution (10 N) of zinc chloride as flux; for small samples this s preferably carried out by dipping the semiconductor in a solder bath held at 190–200° C. The tinning extends over the whole of the region plated, so that intricately shaped sections of the semiconductor surface may readily be coated with a metallic contact; this is the principal advantage of the method in the case of germanium. It is convenient to leave the polystyrene mask in place until the tinning is complete; this protects the untinned region from spluttered flux and solder.

The contacts have been found to possess a high mechanical strength: when a lead–wire soldered to a contact was subjected to increasing tension, failure frequently occurred within the body of the semiconductor at loads of the order 1000 lb/in.^{2} Surfaces of coarser finish yielded still more tenacious contacts. Using this method, it has not been possible to apply contacts to surfaces which have been chemically or mechanically polished.

The electrical properties of the contacts are specified in terms of the following measurements. Two contacts were placed on opposite faces of a thin slice of the semiconductor, and a current caused to flow between them; the voltage drop at one of the contacts was measured by a high-impedance voltmeter connected between it and an auxiliary contact to the semiconductor. In this way the current-voltage characteristic of a contact was obtained, and the contact resistance calculated. The following table shows typical results for the conductance per unit area of contacts.

Metallic contacts to germanium and silicon

Material	*Resistivity* (Ω cm)	*Contact conductance* (mho cm^{-2})
n-type silicon	3×10^{-2}	3
p-type silicon	1·5	0·4
n-type germanium	1·5	20
n-type germanium	3×10^{-2}	75
p-type germanium	2×10^{-2}	300

The characteristics of the contacts for the two directions of flow of the current were linear within 10% up to current densities of 100 mA cm^{-2}, with the exception of *p*-type silicon, for which the value was only 5 mA cm^{-2}. Contacts formed by this process in general show a higher contact resistance than those described by Sullivan and Eigler,* but in our experience are simpler to apply.

It was observed that slight changes only were produced in the conductance of the contacts when fired in hydrogen at temperatures up to 700° C, except for the contacts to *p*-type silicon samples; in this case the conductance was reduced to one-tenth its value before firing.

* Sullivan, M. V., and Eigler, J. H. *J. Electrochem. Soc.*, **104**, p. 226 (1957).

The mounting of fibres and organic crystals for spectroscopy in the near infra-red region

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[*Note received* 4 *March*, 1958]

In order to obtain satisfactory absorption spectra with polarized radiation in the 1·5 μ to 3 μ region, specimens should usually be 0·1 to 1·0 mm in thickness. With fibres, a number have to be mounted parallel and in an immersion medium to reduce the amount of scattered radiation; if very fine fibres are being examined the number required is considerable. For single crystals an immersion medium is desirable and it is necessary to be able to mount the crystal in a particular orientation. The following simple techniques have been found to work satisfactorily when used with a spectrometer fitted with a reflecting microscope giving ×5 magnification.

For mounting fibres, narrow tapered tubes are first made by drawing points on 0·5 cm diameter glass tubing. These can be made in pairs with the points at the ends sealed off, and thereby kept clean until needed. Lengths about 2·5 cm long and tapering from about 3 mm to 0·5 mm are then cut, both ends being open. The ends of a loop of fine wire are pushed down from the wide end of the tube and the fibres to be examined passed through the loop. They are then pulled down tightly into the tube by the wire so that they become parallel. The tube is filled with an immersion liquid by placing a few drops in the wide end which are then drawn down by capillary attraction, air bubbles being removed by placing the specimen in a vacuum desiccator which is partially evacuated a few times. With hexachloro-1,3-butadiene which is commonly used there is no need to seal off the tube and having both ends open assists filling. It is almost inevitable that there should be some residual scatter of radiation which has to be compensated for if a "cell in—cell out" or double-beam system of recording is used. For this purpose a piece of glass ground with carborundum is useful, a final match being obtained by rubbing a black-lead pencil on the ground glass.

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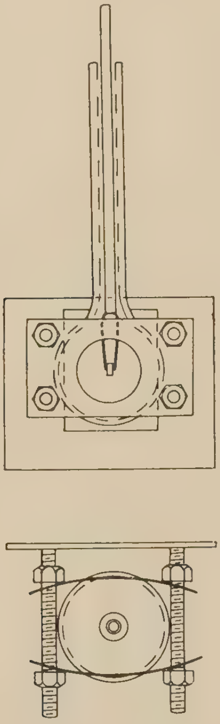
Elevation and plan of cell assembled with a crystal inside

A spherical cell is used for single crystals, made by blowing a bulb of glass on the end of a glass tube of about 4 mm outside diameter. The bulb should be reasonably strong, as uniform and spherical as possible and about 1·3 cm to 1·5 cm in diameter. The crystal is held in the centre by a pair of narrow springy tweezers about 1 cm long, soldered on the end of a stiff brass wire about 16 s.w.g. so that it will slide comfortably down the glass stem. The tweezers are made from thin springy metal and the points should normally press together. By slightly flattening the wire in two or three places, it can be made to slide fairly stiffly down the glass tube so that the crystal is held as nearly in the centre of the sphere as possible. To pick up a crystal, the tweezers are best opened with a smooth tapered probe which thus assists also in steadying the points. The cell is filled with carbon tetrachloride or other immersion liquid and the crystal carefully inserted, the top then being sealed with fish glue. The bulb is gripped between a pair of thin beryllium/copper strips 1·3 cm wide in holes about 0·9 cm in diameter through which the radiation passes. The strips are held in turn on a rectangular brass plate with a larger rectangula hole in it as shown.

Mounted in this way the orientation of the crystal can b adjusted on the stage of a polarizing microscope befor transfer to the spectrometer. Provided that the aspect it i desired to examine is not obscured by the tweezer points, considerable range of rotation and tilting can be obtaine and a satisfactory image projected on the spectrometer slit of specimens with dimensions of the order of 0·5 mm.

By the use of a spherical cell the full magnification of th reflecting microscope is maintained and there are no seriou aberrations. The cell forms a simple type of Federo mounting and can also be used for qualitative microscopy i the absence of a more elaborate universal stage.

Two capacitance transducer circuits

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[*Note received* 18 *February*, 1958]

Mechano-electrical transducers of the variable capacitanc type have to be used in special circuits if a d.c. voltage outpu is required. This note describes two such circuits with widely differing applications.

The first circuit (Fig. 1) is intended for use with a transduce consisting of two pairs of fixed plates and one insulated moving plate. Such a device has the advantage that no electrical connexions need be made to the moving parts, and therefore no additional mechanical constraints are imposed. One pair of fixed plates is energized from a push-pull oscillator, while the moving plate acts as a probe, sampling the potential between them. The other pair of fixed plates transfer this potential to the input of an amplifier. Such a system is only linear, however, if the input impedance of the amplifier is infinite. Otherwise, loading of the very high and variable output impedance of the transducer will occur. The input capacitance of the amplifier is therefore cancelled out(1) by positive feedback *via* C_1; the grid resistance of the amplifier is sufficiently high to be neglected. The output of the amplifier is fed to a phase-sensitive rectifier, the reference signal of which is provided by the oscillator. The output of the rectifier is smoothed to form the output of the circuit.

The circuit is set up as follows. With the amplifier input earthed, P_1 is adjusted for zero output. Differences between the rectifiers are thereby compensated. Capacitor C_1 is then adjusted for best linearity; this can conveniently be done with a sinusoidal mechanical input to the transducer, C_1 being adjusted for minimum harmonic content in the output. With a moving plate of 2·5 cm diameter and a fixed plate spacing of 4 mm, an output voltage of 7 V/mm displacement is obtained. The linear range is about ±1 mm. It should be noted that when the moving plate is central, a truly zero output is obtained; no problems of "backing-off" a standing voltage arise.

The second circuit (Fig. 2) is intended to operate with transducers having a very small relative change of capacitance. It was first used with the capacitance manometer designed by Hansen(2, 3, 4) where the total change of capacitance is about 1 pF in 40 pF. The circuit is effectively a re-design of one due to Kaiser,(4) but using a type of valve which has only recently become available. The basic principles of the circuit remain Kaiser's.

The transducer forms part of a tuned circuit which is kept in oscillation by the type 6J6 valve. The tapping-down of the cable on the tuned circuit minimizes the effects of small nges of cable capacitance. The oscillation is fed to a e 6BN6 gated-beam discriminator valve,(5) the anode rent of which depends on the deviation of the oscillation quency from the resonant frequency of L_1C_1. The iable resistance P serves to set the output voltage to zero h the oscillator switched off; this adjustment minimizes effects of change of oscillation amplitude. With the illator on, C_2 is adjusted to bring the output voltage to ero again, bringing the circuit into the centre of its linear nge.

With this circuit an output of 10 V/pF change of capacitance obtained. The drift of output, after an initial warming-up eriod of ten minutes, is less than 20 mV/h when the circuit operated from batteries.

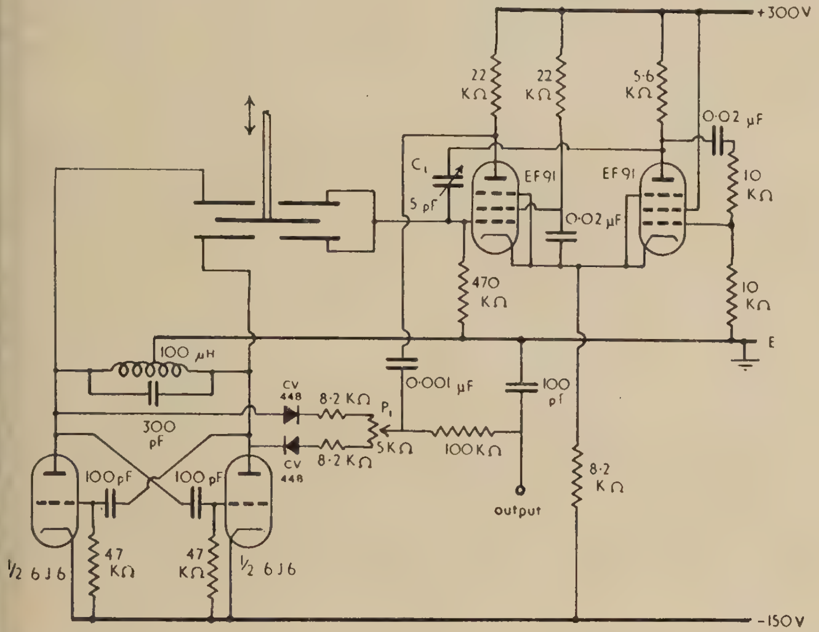
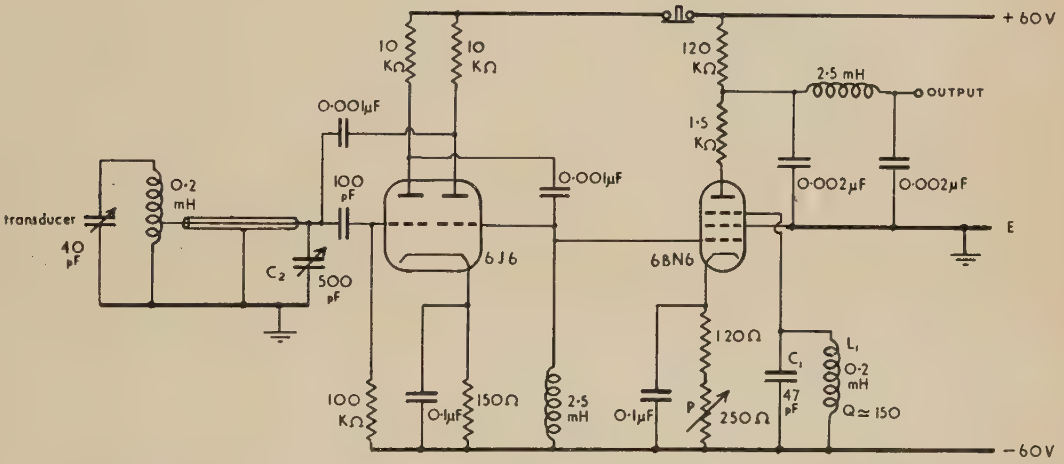

+300V
22 KΩ
22 KΩ
5·6 KΩ
0·02 μF
C1
5 pF
EF91
EF91
0·02 μF
10 KΩ
470 KΩ
10 KΩ
E
100 μH
0·001 μF
100 pf
CV 448
8·2 KΩ
P1
300 pF
5KΩ
100KΩ
CV 448
8·2 KΩ
100 pF
100 pF
8·2 KΩ
output
47 KΩ
47 KΩ
½ 6J6
½ 6J6
-150V

Fig. 1. Circuit for use with floating-plate transducer

Fig. 2. Frequency-modulation circuit


+60V
10 KΩ
10 KΩ
120 KΩ
2·5 mH
OUTPUT
0·001μF
1·5 KΩ
0·2 mH
100 pF
0·001μF
0·002μF
0·002μF
transducer
40 pF
E
C2
500 pF
6J6
6BN6
120Ω
C1
L1
0·2 mH
100 KΩ
0·1μF
150Ω
2·5 mH
0·1μF
P
250Ω
47 pF
Q≃150
-60V

I am indebted to Dr. G. M. Hughes for his collaboration n the development of the second circuit.

REFERENCES

1) Bell, P. R. "Negative Capacity Amplifier" in *Waveforms*, by Chance and others, p. 767 (New York: McGraw-Hill Book Co. Inc., 1949).

2) Hansen, A. T. *Acta Physiol. Scand.*, **19**, p. 306 (1950).

3) Hansen, A. T. *Acta Physiol. Scand.*, **19**, p. 333 (1950).

(4) Hansen, A. T. *Pressure Measurement in the Human Organism* (Copenhagen: Teknisk Forlag, 1949).

(5) Johnson, L. W. *Wireless Wld*, **63**, p. 23 (1957).

Note added in proof. My attention has been drawn to a circuit due to V. H. Attress [*Electronic Engng*, **27**, p. 308 (1955)]. This is similar in principle and performance to those of Kaiser(4) and the present author (Fig. 2). However, the circuit described here is more economical in components and power supplies, without any corresponding loss of sensitivity.

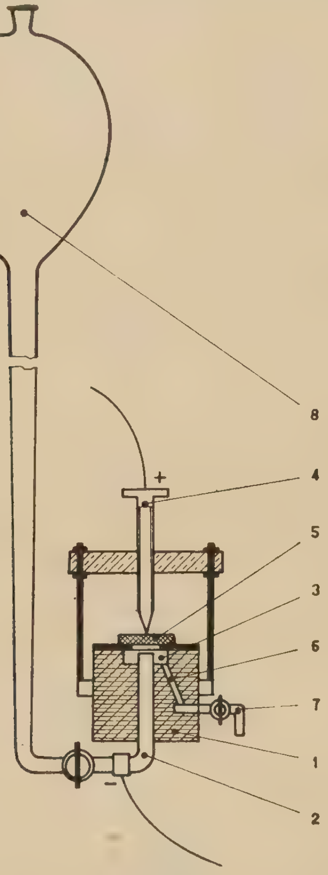
A simple apparatus for electrolytic polishing of metallographic specimens

By F. Brossa, Dr. Chem., and C. Sari, Dr. Chem.,
Instituto Elettrotecnico Nazionale Galileo Ferraris,
Torino, Italy

[*Note received* 17 *March*, 1958]

It is well known that in many cases electrolytic polishing has several advantages over mechanical polishing. Several types of electrolytic polishing apparatus are commercially available, but their price is quite high. We have therefore tried to make a very simple device which suits our laboratory needs (see figure).

The main body (1) is made of insulating Araldite which is not attacked by the polishing liquid and is practically unaffected by temperatures up to 120° C. A 6 mm hole is drilled through the centre of the main body and terminates in a cavity (3) which is 3 mm deep and 11 mm in diameter.



Apparatus for electrolytic polishing of metallographic specimens

A stainless steel pipe (2), screwed in the hole and joined to a separator funnel, is used as the cathode and takes the polishing liquid from the container (8) to the cavity (3). The top of this cavity is closed by the metallographic specimen (5) and held by the screw (4) on to a hollow polythene disk. The polishing solution flows over the specimen surface, then through the drain (6) and tap (7) into a vessel from which it can be recovered. The stainless steel pipe (2) used as the cathode eventually becomes covered by a metal layer, necessitating the reversal of current for a short time every eight or ten polishings.

Good results have been obtained with this apparatus, on many different metals, using unusual baths. For example, we give details on the experimental conditions to polish metallographic specimens of electrolytic iron, silicon iron and aluminium alloys:

Electrolytic iron and silicon iron. The electrolytic bath is an alcoholic solution with 5% nitric acid, 15% hydrochloric acid and 1 g of ferrous chloride. The voltage required is 32 V, the area about 1 cm^2 and the distance between anode and cathode 3 mm. The solution is satisfactory at temperatures ranging from 20 to 35° C, and 300 cm^3 of solution are sufficient.

Aluminium and its alloys. The preceding bath is useless for these alloys, because the surface of the specimen is covered by a layer of oxide, but an alcoholic solution with 20% acetic acid, 10% magnesium perchlorate and 70% ethyl alcohol gives excellent results. The other conditions are the same as for iron specimens: voltage, 32 V; polished area, 50–80 mm^2; and distance between the electrodes 3 mm. The solution is active also at temperatures as high as 40–50° C, but, considering the composition of the bath, it is wise not to exceed these temperatures.

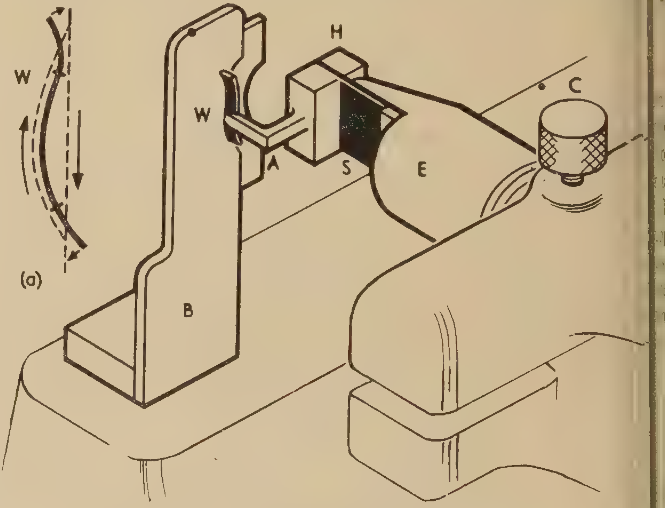
A modification to the Cambridge rocking microtome to facilitate the cutting of thin sections for electron microscopy

By E. H. Mercer, A.Inst.P., Chester Beatty Research Institute, (Institute of Cancer Research: Royal Cancer Hospital), London, S.W.3

[*Note first received* 18 *March and in final form* 21 *April*, 1958]

There are on the market a number of microtomes designed to cut sections thin enough (about 500 Å) to be used for electron microscopy, but all are very expensive. The need for cheaper devices is widely felt and some have been described. In practice, however, these tend to evolve elaborately and difficulties arise.

The familiar, inexpensive rocking microtome (by Cambridge Instrument Co. Ltd.) has been shown to possess the required mechanical stability* and, as an accessory, a finer toothed advancing wheel is available to give advances of the required order. A great drawback remains in that the block must pass over the knife edge on its return stroke ("double pass motion"), leading to scratching and to trouble with the water of the bath used to float off the sections. In practice this is overcome by exerting a slight pressure to separate block and knife sufficiently on the back stroke. This trick demands a certain judgment and at times is irritatingly



A view of a portion of the microtome showing details of the modifications

E is an existing specimen holder cut away at one side as shown; *H* is the new nose piece mounted on the strip of spring steel *S*; *A* is the deflecting hook which engages the cam *W*. The path followed by the deflecting hook when it engages the cam is shown at inset (*a*). The glass knife and holder are not shown.

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* Birbeck, M. S. C. *J. Roy. Micr. Soc.*, **71**, p. 421 (1951).

ffective. The device to be described produces a "single-ss" motion and fits immediately on the existing microtome. To an existing specimen holder *E*, cut back as shown in figure, is added a new nose piece *H* mounted on a vertical ip of spring steel *S*. On the back stroke a hook *A* at the e of the nose piece, by engaging a cam *W*, pulls the block one side, causing it to clear the knife. The path of the d of the hook in relation to the cam surface is shown in et (*a*). At the ends of the cam, flexible tongues guide the ok on to the appropriate surface at each end of its stroke e inset (*a*)]. The cam itself is carried by the upright *B* ld firmly by a single bolt, which may be loosened for justments. The force required to deflect the nose piece is t large and a cam made from 5/1000 in. steel spring lasts veral months.

A merit of the device is that no alterations are made to icrotome mechanism and that in use one proceeds precisely with the normal set-up. The screw *C* is loosened, the lder *E* withdrawn, the specimen is mounted on the nose ece *H* with wax, trimmed to a square end ($\sim 0 \cdot 5$ mm^2) d returned to the instrument. A glass knife and water ough are used in the usual way. No difficulty is experienced cutting ribbons of silver sections (about 250 Å) immediately ter commencing operations.

The writer wishes to thank Mr. A. L. Stewart for making e alterations and Mr. M. S. C. Birbeck for his help with e design.

A modified X-ray powder camera

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[*Note received* 18 *April*, 1958]

n X-ray powder camera of a standard type has been odified in order to improve the circularity of the film pporting rings and their concentricity with the axis of otation of the specimen holder.

The modification consists mainly of replacing the existing pper film supporting surface with a solid aluminium alloy isk (½ in. thick), as shown in Fig. 1. The phosphor-bronze pecimen holder (Fig. 2) bears on a stainless steel plate hich is let into the aluminium disk.

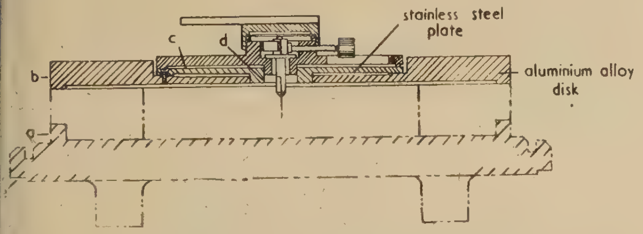

Fig. 1. The modified camera

Faces *a*, *b*, *c*, *d* and *e* are machined at the same lathe setting.

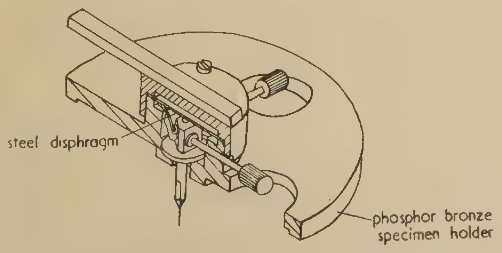

Fig. 2. The specimen holder

The specimen is centred by means of two screw-controlled movements at right angles to each other, working against a single leaf spring. A central downward force on the sliding block is provided by a thin steel diaphragm which bears against a steel ball. The plane of rotation of the specimen holder is defined by its projecting rim and the stainless steel surface, while concentricity is controlled by the short spigot which is an accurate fit in *d*.

In order to ensure circularity and concentricity, surfaces *a*, *b*, *c* and *d* were turned at the same lathe setting as the camera. It is convenient to machine surface *e* also at this setting, to facilitate the alinement of the axes of the camera and of the rotary table used in measuring the angle between the knife edges.

Measurements carried out in the Metrology Division have shown that these modifications are sufficient to make the circularity and concentricity conform to British Standard 1693: 1950, which requires that the axis of rotation of the specimen holder coincides within 0·002 cm with the axis of rotation of the surface on which the film rests, and that this latter surface must itself be cylindrical to 0·002 cm.

The work described above has been carried out as part of the general research programme of the National Physical Laboratory, and this note is published by permission of the Director of the Laboratory.

An apparatus, capable of being heated, for high vacuum grinding of solids

By E. BARONETZKY, Allgemeine Deutsche Philips
Industrie, G.m.b.H., Zentrallaboratorium Laboratorium,
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[*Note received* 21 *April*, 1958]

The apparatus is composed entirely of a high-melting glass, with the exception of the actual grinding mechanism, and may be heated up to 400° C. The drive is based upon the principle of the short-circuit rotor. The construction is shown in Fig. 1, which is reproduced to scale. The sample to be ground, *A* (e.g. a graphite rod), is provided with two guide slots into which slide two pairs of glass notches one above the other on each side as inset (*a*). *B* is a rotary file

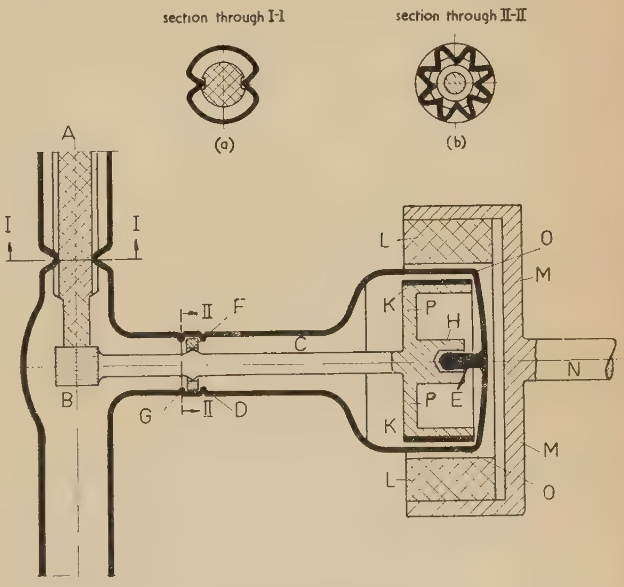

Fig. 1. Grinder

of 10 mm diameter and groove length 13 mm. It is mounted on the spindle C, which itself is supported at D and E. F is a brass ring free to rotate within glass notches at G. Brass may be used up to 300° C, above this temperature the brass ring should be replaced by copper. This ring is 2·2 mm thick and has an outside diameter of 12 mm and a bore of 7·5 mm. The 5 mm thick spindle has a local enlargement here, which is so adjusted to give the brass ring just a slight play. E is a glass rod rounded off in front and fused to the side wall of the glass cylinder in such a way as to be inclined one degree above the horizontal. The wall and the bottom of the cup bearing H are polished. P is a steel cup 45 mm outside diameter and 2·6 mm thick. It is fastened to another local enlargement of the spindle with the aid of a screw. This steel cup is 19 mm long and is surrounded by a cylindrical copper jacket K $\frac{1}{10}$ mm thick and brazed to the steel. It serves as a short-circuit ring. The drive is effected by a Ferroxdure ring (length 25 mm, diameter, inside 52, outside 79 mm). The Ferroxdure is mounted in the 3 mm thick brass cup M, which is driven by N with the aid of a small 1 : 9 geared d.c. electric motor. By varying the current through this motor, the number of revolutions per minute of the brass cup is adjustable from 100 to 600. The Ferroxdure ring attracts the spindle C tightly against the glass rod E, thus ensuring that the spindle remains in its correct position in the bearing F. The mounting of the drive mechanism L–M is installed in such a way that it may easily be removed while heating the glass apparatus and safely remounted in the same position when ready to start grinding.

When sealing the whole device to the vacuum apparatus it has been found convenient to clamp the end O of the glass envelope in the Ferroxdure ring L by means of a thin sheet of paper. The above apparatus has the advantage of being absolutely sealed off without any stop-cocks, taps, ground joints, or gaskets. It is therefore possible to grind in a really high vacuum. The final pressure during this process depends mainly upon the development of gas from the sample and the velocity of pumping; the development of gas from the apparatus itself can be neglected especially when baked out beforehand or after being in use for a long time. The pumping speed may be increased by using a getter near the rotary file.

The grinder described has proved excellent for pulverizing natural and synthetic graphites. It has now been in action more than 150 working hours, at 300–400 rev/min of th drive, without any visible damage on the bearings. Durin operation the vacuum was less than 10^{-6} mm of mercur Some measurements of the slip are given in the grap (Fig. 2), where the moment (g . cm) of the stopped spindle i plotted against the slip (i.e. the number of revolutions pe minute). Fig. 3 represents the magnetic field of t Ferroxdure drive.

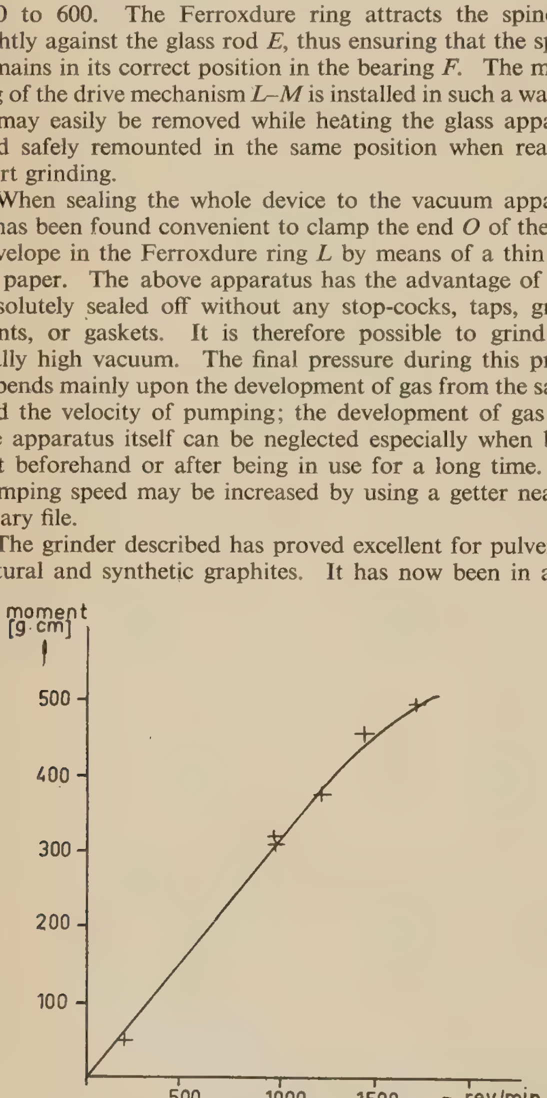

Fig. 2. Efficiency of grinder

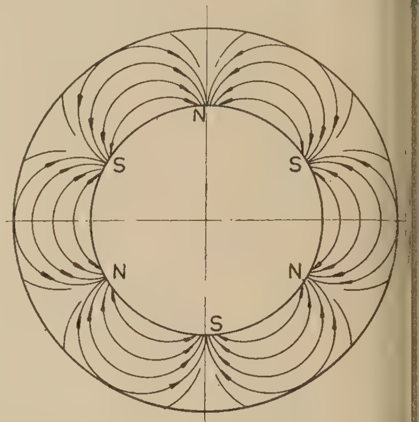

Fig. 3. Magnetic field of the Ferroxdure drive (schematic)

We are much indebted to Ir. M. F. Reynst, of N. V. Philips' Gloeilampenfabrieken, Eindhoven, for constructin the steel cup and the Ferroxdure ring and taking the measurements shown in Fig. 2. This firm also supplied the glass o which the apparatus is made.

The construction of small vacuum leaks of constant value

By R. O. Jenkins, A.R.C.S., D.I.C., Ph.D., F.Inst.P.,
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Wembley, Middlesex

[*Note received* 2 *May*, 1958]

Small leaks with a short path and which will remain constant are required for checking the performance of sensitive leak detectors such as those of the mass spectrometer type, and they can also be used for maintaining a finite and constant pressure in continuously evacuated devices. The following describes a simple method of constructing such leaks without special equipment or unusual materials.

The leak (Fig. 1) consists essentially of a plug of porous metal filling a hole in a mild steel block. The bore of the hole is tinned with soft solder, and a small quantity of soft solder powder is then placed in the hole, one end of which is covered by a flat steel plate. Into the other end is inserted a silver steel rod which should be a sliding fit and this whole assembly is then compressed. The solder powder cold welds

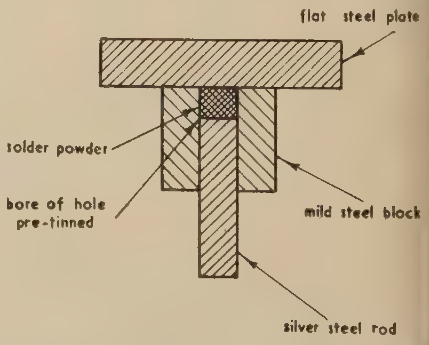


Fig. 1. Method of making the vacuum leak

tself and to the tinned bore of the hole. The rod and the plate are subsequently removed, leaving the end of the filled with the compacted solder powder. Various sizes eak through the porous metal can be achieved, according he pressure applied.

uitable solder powder can be obtained by washing out n a proprietory soldering paste. The pressure necessary th a 4 mm hole can be achieved in ordinary engineer's e, the pressure for a given size leak being then found by al and error. Leaks can be made in a controllable and peatable way using a press with a pressure indicator. (A andrel press, operated with a spring balance might be used.)

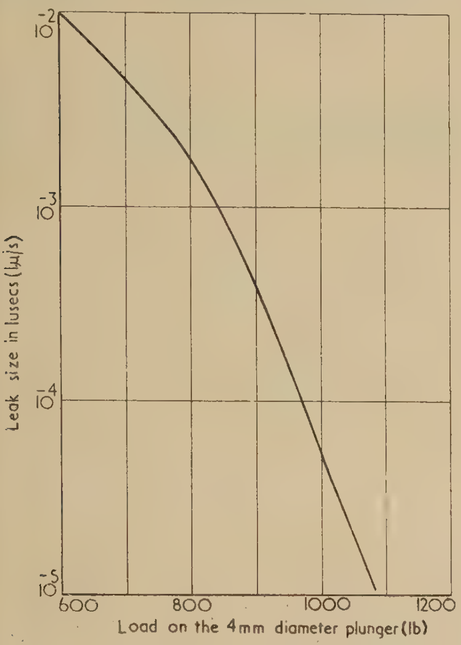


Fig. 2. Leak size against compacting load for 4 mm diameter 1 mm thick compact

With a calibrated press, a curve of leak size against the compacting load for leaks through compacts 4 mm diameter and about 1 mm final thickness was obtained (Fig. 2). Larger leaks could be made by using thinner plugs of larger diameter pressed with a lower load. If a leak is too small in value the compact may be sheared out of the hole by pressure on plunger with the compact unsupported at the other end, and another charge of powder can then be pressed in its place. If the leak is too large it may be repressed at a higher pressure.

There is a tendency for the solder to extrude between the steel component and the plate, when trying to achieve very small leaks. This can be prevented by using a plate with a small boss filling the hole.

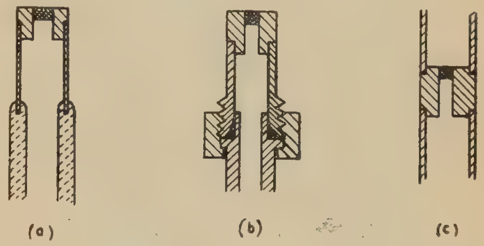


Fig. 3. Method of assembly of the leak

(*a*) Glass-metal seal.
(*b*) O ring seal.
(*c*) Double ended construction.

These leaks can be attached to the vacuum system by low melting point vacuum wax or cold setting epoxy resin. Alternatively the steel component may be soldered on to a glass-metal tubular seal [Fig. 3(*a*)] or to one component of a demountable O ring joint [Fig. 3(*b*)] before the powder is pressed into position. In this case an extension to the plunger will be necessary to project beyond the end of the component. Where it is desired to feed the leak from another closed system a double ended assembly can be made having a suitable vacuum connexion on each side of the steel component [Fig. 3(*c*)].

NOTES AND NEWS

Correspondence

modified mass spectrometer ion source for the study of solid samples

he study of ionization and dissociation processes in vapours ich as those of the alkali halides has recently become of onsiderable interest. Most commercial mass spectro-ieters can, however, only readily deal with gas samples or ibstances that have an appreciable vapour pressure at room emperature. In the present work on alkali halide vapours ie ion source of a Metropolitan-Vickers type MS2 mass pectrometer, normally employed for gas analysis, has been iodified for use with solid samples.

The alkali halide vapour is produced by heating the salt a small oven attached directly to the ionization chamber f the source. The vapour enters the ionization chamber hrough a series of holes in the separating wall between oven nd chamber. This arrangement is seen in Fig. 1, which hows an assembled source before insertion in the mass pectrometer. The oven occupies space normally taken up by the source temperature controller which is not required in the present work. Details of assembly are given in Fig. 2.

The oven is constructed throughout of non-magnetic stainless steel. The body consists of a tube *A* (Fig. 2) welded to a plate *B* which is attached to the side of the ionization chamber. A slot (0·5 × 0·0625 in.) cut in the side of the chamber lines up with five holes (0·025 in. diameter) *C* in the oven. The heater tube *D* is integral with an end plug which is a push fit in one end of tube *A*. A conventional hairpin heater *E*, of the type normally used for indirectly heated cathodes, is inserted in the recess in the heater tube and the ends attached to convenient terminals which were part of the temperature controller system. The salt to be studied is loosely filled into the space surrounding the heater tube. A filler plug *F* is then inserted as a push fit into the open end of the oven tube *A*. In order that the oven can be re-filled without dismantling the source or disturbing the heater filament the filler plug is readily removed by inserting a withdrawing tool in the 6BA tapped hole shown.

With this arrangement the source has now been used satisfactorily for some time and measurements, which will be published elsewhere, have been made on the ions resultin from electron bombardment of lithium chloride vapour.

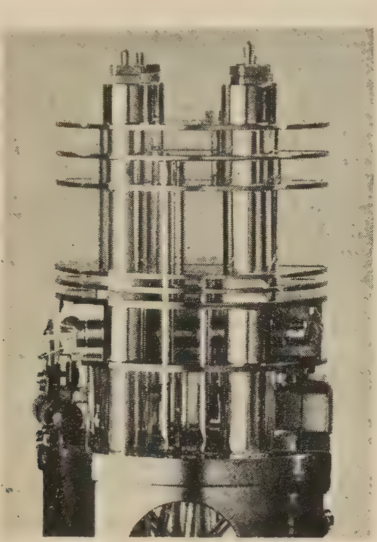


Fig. 1. General view of modified ion source

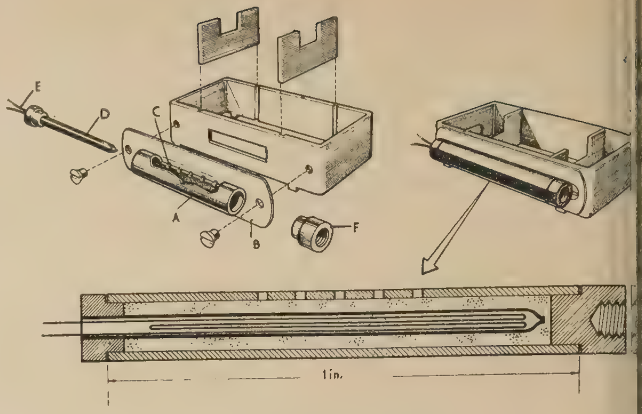


Fig. 2. Details of source oven

We wish to thank the General Electric Co. Ltd., Wembl for a gift of heater filaments used in this work.

Royal Aircraft Establishment,
Westcott,
Bucks.

G. A. Heath
R. M. Hobson*
[2 June, 195

* Now at Clarke Chapman and Co. Ltd., Gateshead.

New books

Theory of electrical machines. By W. S. Wood. (London: Butterworths Scientific Publications, 1958.) Pp. x + 317. Price 50*s*.

A new book on electrical machines is very welcome, especially one written for students, as it is regrettable that the young people today seem to show little interest in machines, but are attracted only by the apparent glamour of such subjects as nuclear energy, electronics and space travel. Yet the 20 million kW of electrical power on which this country depends is all generated by rotating machines, and surely there is some romance in designing and building a machine to generate 275 000 kW on a single shaft. Moreover, many of the basic physical problems (e.g. heat transfer) are the same for conventional machines, nuclear reactors, and rockets.

The book is intended to provide a complete text on electrical machines suitable for final-year electrical engineering students. It opens with a chapter on the fundamental principles of the generation of E.M.F. in machines. Subsequent chapters deal with windings; the effects of load current in armature windings; static transformers; synchronous machines; induction machines; a.c. commutator machines; and d.c. machines (including rotating amplifiers). There are appendices on the starting of synchronous motors; fundamentals of design; and temperature rise. The book concludes with a number of problems (with answers) associated with the various chapters.

The subject is clearly expounded, and the text is well illustrated with an adequate number of excellent diagrams. In the opinion of the reviewer, however, the treatment is too impersonal, and one looks in vain for such famous names as Steinmetz, Blondel, and Kapp. There are only 16 references and the student in search of further information will have to make his own search through the literature. Furthermore, the index is quite inadequate. However, these are minor criticisms, which do not prevent the book from fulfilling i main purpose satisfactorily.

J. S. Forres

The junction transistor and its applications. By E. Wolfe Dale. (London: Heywood and Co. Ltd., 1958 Pp. viii + 394. Price 84*s*.

Roughly one-third of this book, which is written around th alloy-type of junction transistor, is devoted to the physics o transistor operation and the equivalent circuits that may b derived from theory. The remainder deals with the followin topics: direct current biasing and audio-frequency ampl fication; high frequency amplification; class C amplificatior sinusoidal oscillators; amplitude modulation and demodula tion; the junction transistor in non-linear circuits; transisto d.c. converters; and finally, transistor measurements.

The book is the result of the combined efforts of nin contributors and, as may be expected in a book of this type there is inconsistent use of symbols from one chapter t another (this is particularly apparent for the various junctio capacitances), considerable duplication of material an inadequate detailed cross-referencing between the chapters A comprehensive list of symbols would make for consistenc and at the same time help the reader. In Chapter 2, whic deals with transistor characteristics, some erroneous con clusions are drawn concerning the temperature-dependenc of certain device parameters because the temperature dependence of the diffusion constant of minority carriers ha been overlooked.

Theoretical work has been kept at an elementary level an in dealing with practical circuits the contributors hav obviously drawn on their own experience. The book ma therefore be regarded as a useful guide to transistor appli cations and as such will no doubt appeal to students an circuit engineers.

F. J. Hyde

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

C. microvoltmeter. Hewlett-Packard Co., 275 Page Mill Road, Palo Alto, California, U.S.A.

e model 425A meter employs an a.c. amplifier with chopped ut and synchronous demodulation (homodyne) with avy degenerative feed-back. A novelty is the use of a n-mechanical chopper consisting of photo-conductive ments. The modulator is operated at other than supply quency so that mains ripple in the voltage to be measured s little effect. The centre-zero meter has 11 voltage ranges m ±10 μV to ±1 V and 18 current ranges from ±10 $\mu\mu$A ±3 mA, and the makers claim an accuracy of 3% exclusive noise and drift. The noise is stated to be less than 2 μV r.m.s. referred to the input terminals, and the drift s than 2 μV/h. The instrument can operate with floating ut up to 400 V above earth. Indication is on a built-in ter. Output terminals in parallel with the meter enable e instrument to be used as a d.c. amplifier with an output 1 V and a maximum gain of 100 dB in the most sensitive sition of the range switch.

nplitude-modulated signal generator. Marconi Instruments Ltd., St. Albans, Hertfordshire.

e TF 801C generator covers the frequency range of 10 to 0 Mc/s and is claimed to have a tuning accuracy of 0·5% th exceptionally low spurious frequency modulation. The it incorporates a built-in crystal calibrator and the circuit cludes a tuned power amplifier giving an r.f. output of gh purity. Modulation is applied to the power amplifier thout disturbance of the master oscillator. This arrangeent is stated to give freedom from frequency modulation d good response to pulse modulation. The carrier level continuously variable from 0·1 μV to 0·5 V, and 1 kc/s nusoidal amplitude modulation may be applied internally any depth up to at least 30%, and at most carrier freuencies up to 90%. External sinusoidal modulation may applied over the frequency range 30 c/s to 20 kc/s, and e modulation depth can be monitored up to 90%. The odulating circuit is d.c. coupled for pulse modulation, and ill accept pulse repetition frequencies up to at least 50 kc/s.

-ray diffraction camera. H. Morin, 11 Rue Dulong, Paris.

he camera, type 20Q21–ONERA, is of the Seemann-Bohlin pe used in conjunction with a curved quartz crystal monoromator. The instrument is intended for use with powdered pecimens using chromium Kα radiation but slight modications permit its use at other wavelengths. The system is artially achromatized; the Kα_1, Kα_2 doublet is, in fact, not esolved, in spite of good line definition for Bragg angles maller than 46° and rigorous achromatism occurs at a ragg angle of 27°.

The three main parts of the camera are the monochromator, e sample holder and the film cassette. These are mounted n a plate. The plate is normally designed to suit chromium radiation but other plates can be provided for other avelengths. The incident beam falls on the specimen at an ngle of 20° and the diffraction patterns are produced to the cale of 4 mm length corresponding to a Bragg angle ifference of 1°. In order that the camera may be operated *n vacuo* a cover is provided which is fitted with a beryllium indow.

Rapid processing photographic projector. Kelvin and Hughes Ltd., New North Road, Barkingside, Essex.

Designed in conjunction with the Ministry of Supply, this equipment facilitates the large scale presentation of photographically recorded and processed sequential events as they appear on a cathode-ray tube. A 35 mm film can be processed and projected with the minimum of delay on to a screen of suitable size according to the intensity of the illumination required. A positive or negative image is available to suit personal preference or to conform to the admissible levels of ambient light. Although the equipment has been generally used with conventional cathode-ray tubes, it is suitable for recording the fast read-out from a Charactron-shaped beam tube or other similar device. The cathode-ray tube presentation may be, for example, a Plan Position Indicator radar display on a long persistence tube, or any other form of presentation, such as a data processing display or other instantaneous picture.

The apparatus has civil applications embracing air and marine traffic control and, linked to electronic computing equipment, in industrial and research projects. Completely self-contained and fully automatic, the apparatus takes 1000 ft reels of film which at a normal film speed of four exposures per minute, gives it a continuous operating period of approximately 24 h. Integral reservoirs permit the replenishment of chemicals without stopping the machine.

The film record is projected by means of a lens, illuminated by a compact source mercury-xenon arc lamp. The image can be projected through 90° by means of a silvered prism, facilities for rear projection being provided. The illumination on a 5 ft diameter screen is about 100 candles/ft^2. Projection lenses are normally available in focal lengths of 25, 32, 40, 50 and 75 mm. These are supplied in interchangeable focusing mounts. Normally the projectors are operated in pairs, so that a continuous display is assured, optical registration of the projector being achieved by means of a double-sided mirror, common to both equipments.

For negative processing, the operational cycle time is 6 s, while for positive processing the cycle time is 12 s. These times can be shortened, but the results may be at the expense of contrast and permanence. New types of film for use in the equipment have been developed by Ilford Ltd., working with Kelvin and Hughes Ltd. A fog level of 0·05 or less is obtained for positives or negatives. A maximum density of up to 2·5 is obtainable for a negative in a 15 s cycle, whereas a projection density of 1·5 may be obtained for the positive process.

Remarkably high resolution is claimed; for example, substituting a test card for the face of the cathode-ray tube, positive and negative presentations were obtained which clearly resolved 1400 lines across the picture at f/2 and 2000 lines, i.e. 1000 black and 1000 white, at f/4 as viewed on the projected picture.

Television camera for closed-circuit applications. Marconi's Wireless Telegraph Co. Ltd., Chelmsford, Essex.

The type BD871 television camera channel has been designed with particular attention to simplicity of control and reliability. The new equipment is of two-unit construction, comprising the camera proper and its associated control unit.

The camera unit is contained in a small steel cylinder 4 in. in diameter and 11 in. long, and the control box measures 14 × 17 × 8 in. The "eye" of the camera is a 1 in. Vidicon pick-up tube (by English Electric Co. Ltd.), which, with the scanning coils and head amplifier, makes up the camera unit. The encasing cylinder acts as a dustproof container and as a shield against stray magnetic fields.

One feature of the equipment is the incorporation of automatic sensitivity control, which is said to compensate for wide variations of lighting levels without recourse to the adjustment of the manual controls and enable the equipment to operate completely unattended. Focusing can be carried out by means of an adjustment at the rear of the camera, or, if desired, by remote control; in the latter event an additional unit, 3 in. in length and of the same diameter as the camera, is fitted on to the end of the latter. The camera control unit can be installed at any convenient location up to 1000 ft away; control adjustments can either be effected at this point or, by making use of a special "detached control" feature in the equipment, at any chosen spot within 500 ft of the camera control unit. A modification allows this length to be extended if circumstances make it desirable.

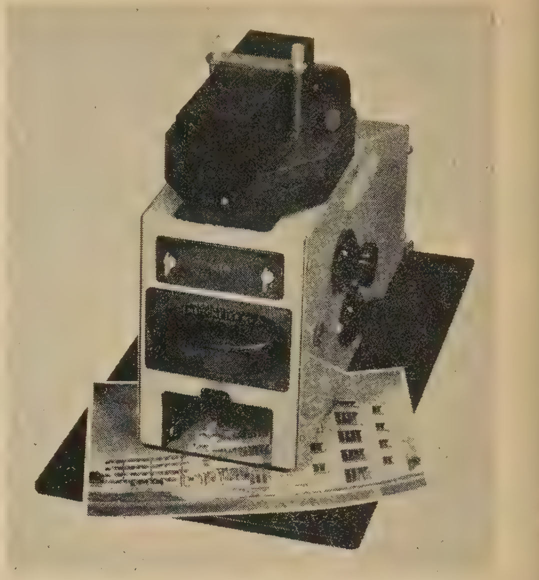
The type BD871 equipment will operate on either British, American or C.C.I.R. standards. The display screens can either be monitors operating with a video frequency or 20 Mc/s input, or standard television receivers.

Reflexion densitometer. Baldwin Instrument Co. Ltd., Brooklands Works, Dartford, Kent.

A new version of reflexion densitometer has been produced for measuring colour of a wide variety of materials. A four-position rotary filter holder is fitted on to the instrument between the shutter and the photocell and the unit is normally supplied with three tri-colour filters (by Ilford Ltd.). The filters are located in position by means of a positive index and when in position a colour signal on the front of the holder indicates which particular filter is being used. If it is necessary to use more than three filters the rotating disk can easily be replaced by another holding a different set of filters.

The filter holder is constructed from a heat insulating material which isolates the photocell from the heat of the lamp, thereby preventing the drift which may otherwise occur due to the temperature dependance of the photocell. The holder has been so designed as to allow it to be fitted easily to existing density units.

The reflexion densitometer makes use of the Baldwin vacuum cell photometer which is essentially a stable d.c. amplifier. The output from this amplifier is fed to a movin coil meter which is calibrated in units of density and illumination. One feature of the photometer is a meter whic



can be fitted having shaped pole-pieces which produces a almost logarithmic response; thus the density scale is almos linear throughout its range.

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A thermometer for high-speed aircraft

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The principles of aircraft thermometer design are reviewed, from which it is deduced that the conical head design possesses distinct advantages over other kinds of thermometer head in high-speed flight. The construction of the thermometer is described and the results of wind-tunnel tests are quoted and discussed. The lag and radiation errors are calculated and the extension of the use of the thermometer to supersonic flight is discussed. An outstanding feature of this thermometer is the remarkable constancy of the recovery factor over a range of Mach numbers from 0·2 to 0·9 and its rapid response to temperature changes, the lag coefficient being of the order of 2 s.

thermometer mounted on an aircraft to measure air nperature reads high by an amount given by the expression

$$T_s - T_0 = \frac{\lambda}{2C_p} U^2$$

ere T_0 is the true air temperature in degrees C, T_s is the nperature of the thermometer surface in degrees C, U is air speed in cm/s and C_p is the specific heat of air at nstant pressure. λ is usually referred to as the "recovery tor" since it can be expressed as the proportion of actual nperature rise to total temperature rise of completely rested air, i.e.

$$\lambda = (T_s - T_0)/(T_2 - T_0)$$

ere T_2 is the temperature of the air arrested adiabatically. practice, when the air speed is measured in knots and the nperature in degrees Celsius, the expression for the nperature rise is usually written as

$$T_s - T_0 = \alpha\left(\frac{V}{100}\right)^2$$

Here α is called the speed-correction coefficient. Whereas e value of λ, in relation to the aerodynamic parameters ch as Mach number and Reynolds number, depends only the characteristics of the thermometer, α also depends on $_p$, the variation of which, however, is small, so that, very arly, $\alpha = \frac{4}{3}\lambda$.

For speeds up to about 200 miles/h, errors in temperature hich would arise from errors in the value assumed for λ e not important. However, at high speeds, say 500 miles/h, error of 0·1 in λ would give rise to an error in temperature about 3 degrees Celsius. Variations of the order of 0·1 in with altitude and air speed are quite usual on present aircraft ermometers and may be due to a variety of reasons. These riations were first reported by Shellard(1) and have been scussed by the present writer.(2) The effect of variations λ can be overcome to some extent by calibrating the ermometer for different heights and Mach numbers. evertheless it is better to try to reduce or eliminate these riations by careful design.

There are two possible forms that an aircraft thermometer n take. Either it can arrest the air completely, causing an iabatic temperature rise corresponding to the resulting mpressional heating, or else it can interfere with the air ream as little as possible so that the air speed past the ermometer is unchanged and the temperature rise depends on the balance of the energy dissipated and heat conducted within the boundary layer on the surface. The first type is called a total head thermometer, and the second type a flat-plate thermometer.

The first variety has been studied very thoroughly by several authors such as E. Brun and Max Plan,(3) and L. Malmquist,(4) and although it is generally favoured for laboratory work, nevertheless, for meteorological purposes, it has certain disadvantages. In construction the total-head thermometer consists of a hollow chamber open at the forward end and with leak vents at the rear to maintain a slight air movement inside. The temperature of the arrested air is measured by a rapid response element such as a bare resistance wire or thermocouple junction. It is difficult to make a design of this nature robust without sacrificing speed of response and it is essential that response be rapid owing to the low ventilation rate within the chamber. As has been shown by Malmquist,(4) the recovery factor of these thermometers suffers significant changes with Mach number attributable to the nature of the flow inside the chamber. Also, the recovery factor, which is always slightly less than it would be if the air were completely arrested, is dependent on the rate of ventilation which bears a non-linear relationship to the free air speed. This thermometer is, moreover, vulnerable to ice formation and, once iced up, takes some time to clear unless heaters are fitted for de-icing.

An advantage claimed for the total-head thermometer is that radiation shielding of the heated air in the thermometer chamber is a simple matter, whereas with the flat plate, although the temperature rise is smaller, the presence of effective shielding constitutes an obstruction which is not practical at high speeds. Fortunately the high rate of heat exchange at the surface of the flat-plate allows other methods of radiation protection than shielding to be employed; it also permits robust construction without sacrificing speed of response.

The total-head thermometer is largely independent of local air speed and small deviations of direction of flow from the axial, but the flat-plate thermometer is sensitive to local air speed and direction, and on this account requires a careful choice of mounting position which will ensure that it faces into the undisturbed air stream and is alined axially.

Although the total-head thermometer appears at first sight to have the advantage of representing a fundamental approach to the problem of temperature measurement in a moving air stream, in so far as it is dependent only on the total energy of the air and not on local stream velocity, nevertheless the constructional compromises required in the engineering of a total-head thermometer make it inferior to a well designed flat-plate thermometer.

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CHARACTERISTICS OF FLAT-PLATE THERMOMETERS

A flat-plate thermometer, designed by Brewer,(5) has been in regular use aboard meteorological aircraft for many years and gives reliable readings to the nearest half degree Celsius at air speeds up to about 300 miles/h. It is made from a ½ in. metal tube flattened to ⅛ in. thick, containing a platinum resistance wire element insulated by mica strips.

Shellard(1) found that the speed correction of this thermometer was less at high altitudes than at low altitudes. A plausible explanation of these variations in λ would be the changes in energy dissipation and heat exchange in the boundary layer brought about by transition from laminar to turbulent flow as the Reynolds number increases from high to low altitudes.

For example, in laminar flow, in the boundary layer on a flat-plate, the expression for λ is

$$\lambda_L = 1 - \left(\frac{u_1}{u_0}\right)^2 (1 - \sigma^{1/2})$$

where subscript 1 refers to conditions near the surface and 0 to the undisturbed flow, and where σ is the Prandtl number.

This expression for λ is obtained from Pohlhausen's(6) formula for the temperature rise at a flat-plate, assuming constant density, with no heat exchange at the surface, namely

$$T_s - T_1 = \sigma^{1/2}(u_1^2/2C_p)$$

together with the energy equation

$$T_1 + (u_1^2/2C_p) = T_0 + (u_0^2/2C_p)$$

Crocco(7) showed that this formula for λ held also in a compressible medium and therefore is valid at all speeds.

The equivalent expression for λ for a turbulent boundary layer has been given by Squire,(8) as

$$\lambda_T = 1 - \left(\frac{u_1}{u_0}\right)^2 (1 - \sigma^{1/3})$$

There is every reason to believe that this formula also holds at all speeds, provided no marked pressure gradients are present.

Now since σ does not vary by more than 0·01 within the atmosphere (Clark(2)) we can write that very nearly $\sigma^{1/2} = 0{\cdot}84$ and $\sigma^{1/3} = 0{\cdot}89$; whence for a thin flat-plate, well sited, the recovery factor would be expected to change from 0·84 to 0·89 with a complete change from laminar to turbulent flow in the boundary layer. In practice, of course, the corresponding values of the recovery factor would be less than this owing to the air speed past the surface being greater than the free air speed.

On the flat-plate thermometer of the flattened-tube variety, a change from laminar flow is usually initiated by a separation of the boundary layer from the surface behind the leading edge. That changes from laminar to turbulent flow over a flattened-tube type of flat-plate do, in fact, occur for the range of Reynolds numbers corresponding to conditions of normal flight at high and low altitudes can be demonstrated using a photographic technique in a wind tunnel.

The importance is seen, therefore, of maintaining uniformity in boundary layer flow—either all laminar or all turbulent; but because of the sporadic nature of boundary layer transition, described for example by Dryden(9) or Emmons,(10) and the uncertainty of turbulence inducin devices (not to mention the encumbrance they add to small shape such as a thermometer), it is much preferable t endeavour to maintain laminar flow. The small gain i speed of response due to turbulence in the boundary layer i less important than the stability induced by laminar flow.

TEMPERATURE GRADIENTS

When a thermometer is in thermal equilibrium with th air stream, the condition that there be no heat exchang taking place between the ambient air and the thermomete surface, apart from small losses, is that no temperatur gradients should exist on the surface, because their presenc would require surface heat conduction giving rise to corresponding compensating heat exchange with the air stream.

Since the rate of heat exchange (which is proportional t $k/\nu^{1/2}$, where k is the thermal conductivity and ν the kinematic viscosity of the air) is less at high altitudes than it i at low altitudes, the temperature gradients on the thermometer surface will also change with altitude, becoming les pronounced higher up. The mean temperature, of course depends on the temperature distribution on the thermomete surface and is likewise affected. The result, therefore, of th presence of temperature gradients on the thermometer is a apparent variation in recovery factor with altitude, which however, becomes noticeable only when these gradients ar well-marked.

Care must therefore be taken to avoid designs which giv rise to pronounced temperature gradients and to reduce to a minimum, the effects of such temperature gradients as exist

SPEED OF RESPONSE

In the atmosphere there can exist temperature changes i the horizontal of about 2° C every 5 miles or so and occasionally extreme variations of 4° C can occur in only 1 mile If a thermometer is being designed to read to within ½° C of true indicated temperature with a horizontal temperatur change of say 4° C in 1 mile, then, at 200 miles/h at low altitudes, the lag coefficient would have to be less than 2·25 s, and at 500 miles/h, less than 1 s. Assuming that th lag coefficient is inversely proportional to the square root o the air speed then 2·25 s at 200 miles/h is equivalent to 1·4 at 500 miles/h, which is too great. In fact to obtain 1 s a 500 miles/h, which is required, would mean having 1·58 s a 200 miles/h. Because the lag coefficient also varies inversel as the square root of the air density, a lag of 1 s at 500 miles/ at low altitudes becomes 2·75 s at the same speed at 100 mb

In the design which was finally adopted a compromise between robustness and speed of response gave a la coefficient of about 2 s at low levels at 200 miles/h. This la coefficient corresponds to the temperature errors given i Table 1, calculated for temperature gradients, in the line o

Table 1. *Temperature errors due to thermometer lag calculated for a lag coefficient of 2 s at 900 mb, and a 200 miles/h, with temperature gradients of 4° C per mile and o 0·4° C per mile*

Speed (miles/h)	*Pressure level* (mb) 900		100	
	Temperature gradient		*Temperature gradient*	
	(4° C/mile)	(0·4° C/mile)	(4° C/mile)	(0·4° C/mile
200	0·44	0·04	1·22	0·12
500	0·69	0·07	1·93	0·19

ht, of 4° C in 1 mile, and, also, of 0·4° C in 1 mile, at ssure levels of 900 mb and 100 mb, and for air speeds of and 500 miles/h, using the formula

$$\Delta T = Ug'L$$

ere ΔT is the lag error, U the air speed, g' the temperature dient and L the lag coefficient.

THERMOMETER DESIGN

he essential points in the design of a good flat-plate type thermometer are therefore the following:

1) The boundary layer of the air flow over the thermometer must be encouraged to stay laminar, i.e. there must not be a positive pressure gradient, but preferably there should be a slight negative pressure gradient.
2) There should not be any temperature gradient or, if that is impossible because of (1) the effect should be kept as small as possible.
3) The speed of response to temperature change must be rapid.
4) It must be robust and simple in construction.

he simplest design embodying the above points was ained by adopting a conical shape for the thermometer d. A cone of 20° offered a convenient size from a conictional point of view, so this size was studied in greater ail. The velocity component along the surface of a 20° ie was calculated from the solution to Laplace's differential iation for a compressible fluid flow with axial symmetry ich E. V. Laitone[(11)] derived using the linear perturbation thod of Goldstein and Young.

aitone's solution applied to the flow round a cone gives, the velocity potential,

$$\phi = u_0 x - u_0 \frac{\tan^2 \psi}{2} \int_0^c \frac{\xi d\xi}{[(x-\xi)^2 + (\beta r)^2]^{1/2}}$$

ere ϕ = velocity potential
u_0 = velocity remote from the cone
$\beta = \sqrt{(1 - \mathrm{M}^2)}$; M = Mach number <1
c = length of the cone from tip to base
x = a specified distance along the conical axis from the tip
u_1 = velocity component along the conical surface corresponding to the distance x
ξ = any distance along the conical axis from the tip
2ψ = apex angle of the cone = 20°

e square of the velocity component $(u_1)^2$ given by

$$u_1^2 = \phi_x^2 + \phi_r^2$$

ere suffices x and r denote partial differentiation with pect to those variables, was calculated and the expression $-\left(\frac{u_1}{u_0}\right)^2$ is shown plotted in Fig. 1. Although ϕ is a iction of c and x/c, ϕ_x and ϕ_r are functions of x/c only any given value of ψ.

The local surface temperature rise corresponding to the al surface air speed assuming no heat exchange along the face is given by

$$\Delta T_1 = \frac{\lambda}{2C_p} u_1^2$$

If the surface were a flat-plate parallel to the air flow the temperature rise would be

$$\Delta T_0 = \frac{\lambda}{2C_p} u_0^2$$

The ordinate of Fig. 1 therefore, namely $1 - \left(\frac{u_1}{u_0}\right)^2$, is proportional to $1 - \frac{\Delta T_1}{\Delta T_0}$. The flat portion of the curve at about one-third the length of the cone from the tip shows the least temperature gradient. It was considered advantageous therefore to position the temperature sensitive part of the thermometer in that region. In the model tested, the sensitive portion covered a frustrum of about a ¼ in. in a cone of about 1¾ in. in length.

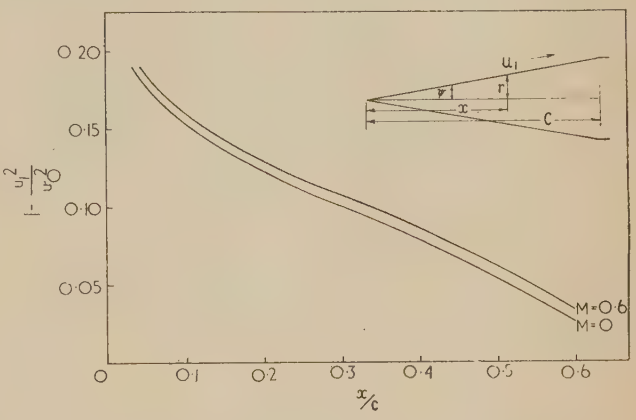

Fig. 1. Variation of surface air speed along the front half of a 20° cone

CONSTRUCTION

In its final form this thermometer was reduced to four separate parts, shown in Fig. 2. The body of the thermometer, consisting of part of the conical surface which terminates in a cylindrical section, is made of a synthetic

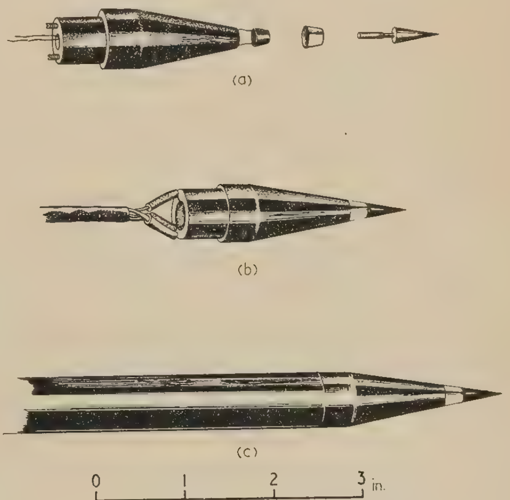

Fig. 2. Conical head thermometer

(*a*) Exploded view showing construction and method of assembly. (*b*) The assembled head with attached cable. Compensating leads are shown in addition to the element leads. (*c*) Thermometer in mounted position.

resin bonded paper material. The sensitive element is made up of a platinum resistance wire of 50 s.w.g. wound on to a thin-walled former made of a super-pure aluminium base alloy, anodized for electrical insulation, on which has been cut a thread of 200 turns/in. The problem of providing leads and anchoring points for the platinum wire, without adding appreciably to the thermal capacity of the element, was solved by clamping copper foil strips to the inside of the former by turning over the ends of the foil into end recesses on the face of the former. These copper foil strips which gripped the former firmly, then provided anchoring points for both platinum wire and leads.

The thermometer head when assembled is held in a brass adapter piece which allows it to be mounted on a suitable support on the aircraft. On later models the tip, which in Fig. 2 is shown in synthetic bonded paper, was made in one piece with a threaded rod of cupro-nickel alloy and was separated from the temperature element by an insulating collar cemented to the tip with an epoxy resin.

WIND-TUNNEL TESTS

The recovery factor of a thermometer is defined in the equation

$$T_s - T_0 = \lambda(u_0^2/2C_p)$$

$$= \frac{\gamma - 1}{2}\lambda\,(T_0 + 273)M^2 \qquad (1)$$

where $0 < \lambda < 1$, T_s is the temperature of the thermometer, T_0 is the air temperature, u_0 the air speed in cm/s, C_p the specific heat of air at constant pressure, $\gamma = C_p/C_v = 1{\cdot}4$, and M is the Mach number, also

$$T_2 - T_0 = \tfrac{1}{2}(\gamma - 1)(T_0 + 273)M^2$$

where T_2 is the total temperature corresponding to the temperature of completely arrested air, assuming adiabatic compression.

Hence

$$T_2 - T_s = (1 - \lambda)\tfrac{1}{2}(\gamma - 1)M^2(T_0 + 273)$$

$$= \frac{(1 - \lambda)\frac{1}{2}(\gamma - 1)M^2(T_2 + 273)}{1 + \frac{1}{2}(\gamma - 1)M^2}$$

Therefore

$$1 - \lambda = \frac{(T_2 - T_s)}{(T_2 + 273)} \cdot \frac{1 + \frac{1}{2}(\gamma - 1)M^2}{\frac{1}{2}(\gamma - 1)M^2} \qquad (2)$$

Equation (2) expresses λ in terms that can be measured in the wind tunnel.

Facilities were obtained at the National Physical Laboratory to test this thermometer in their 8 × 18 in. wind tunnel of the Aerodynamics Division. The total temperature T_2 was measured in the intake chamber with a bare-wire platinum resistance thermometer. T_s represents the temperature measured by the thermometer being tested; and M, the Mach number, was measured on the tunnel Mach number gauge and corrected for tunnel interference effects.

During each run the total-head temperature drift was never more than about one degree Celsius, and the air in the intake chamber was sufficiently near stagnation for no correction to T_2 for air movement to be necessary even at the highest Mach numbers.

The values of λ for each Mach number, calculated using equation (2), are given in Table 2, and are shown plotted in Fig. 3(*a*). The corresponding Reynolds numbers are also given in Table 2 and the variation with Reynolds number is illustrated in Fig. 3(*b*). On the same diagrams are insert
the calculated values of λ for the conical head thermomet
for both laminar and turbulent flow in the boundary lay
obtained from the formulae

$$\lambda_L = 1 - \left(\frac{u_1}{u_0}\right)^2 (1 - \sigma^{1/2})$$

$$\lambda_T = 1 - \left(\frac{u_1}{u_0}\right)^2 (1 - \sigma^{1/3})$$

where u_1 is chosen for $x = c/3$.

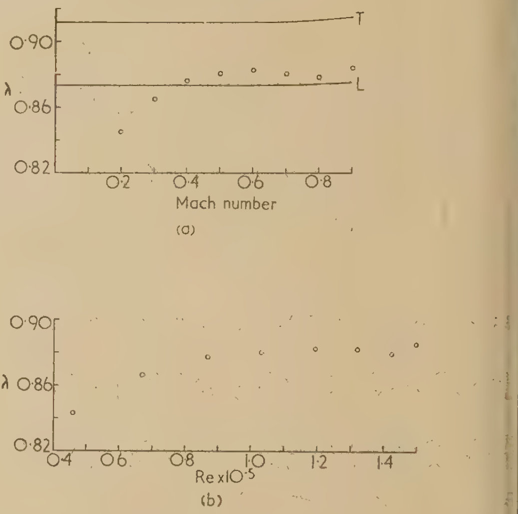

Fig. 3. Recovery factor λ as measured in the wind tunnel

(*a*) Plotted against Mach number. The lines *T* and *L* are the
calculated values of λ for turbulent and laminar boundary-layer
flow respectively, assuming no heat conduction along the
surface. (*b*) Plotted against Reynolds number.

The total calibration and reading error in T_s was found
lie within ±0·043° C and that of T_2 within ±0·015°
whence the standard deviation of λ was calculated, and
given in Table 2. From Table 2 it is seen that the values

Table 2. *Wind tunnel results. Values of recovery factor*

Mach. No.	*Re* × 10⁻⁵	λ	*Number of readings*	$\sigma_1(\lambda)$	δ*T* °C	$\sigma_2(\lambda$
0·2	0·46	0·884	18	0·012	0·08	0·0
0·3	0·67	0·866	15	0·004	0·08	0·0
0·4	0·87	0·875	16	0·002	0·05	0·0
0·5	1·05	0·880	14	0·000	0·01	0·0
0·6	1·20	0·882	11	0·001	0·02	0·0
0·7	1·32	0·882	13	0·000	0·03	0·0
0·8	1·43	0·880	18	0·001	0·04	0·0
0·9	1·50	0·886	15	0·002	0·23	0·0

$\sigma_1(\lambda)$ = standard deviation of λ
$\sigma_2(\lambda)$ = standard deviation calculated from limits of accura
of T_s and T_2
Re = Reynolds number, based on length of temperatu
sensitive part of cone
δ*T* = error in true air temperature which would arise fr
taking λ = 0·881

λ for each Mach number show a slight variation. T
importance of this variation has been assessed by calculati
the errors in true air temperature which would arise if

ıstant value were assumed for λ throughout. For this culation the constant value of λ chosen was the mean for $= 0 \cdot 4$ to $M = 0 \cdot 9$, namely 0·881, and the true air ıperature was assumed to be 8° C. The formula for the ıperature error is

$$\delta T_0 = \delta\lambda(T_0 + 273)\frac{(\gamma - 1)}{2}M^2$$

ese results are also given in Table 2.

The error is seen to be negligible for $M = 0 \cdot 2$ to $0 \cdot 8$ and still small at $M = 0 \cdot 9$. There is justification therefore in igning a constant recovery factor of 0·881 for this ırmometer.

These tests were carried out with the thermometer alined rallel to the air flow. The effect of yaw was not investigated it was considered that this thermometer would be used ınly on meteorological flights where the chance of it being salined would be small.

RADIATION PROTECTION

It is normal practice to protect a thermometer from radia- n by surrounding it with a radiation shield. The presence a shield round a flat-plate thermometer, however, gives e to an increment in air speed over the thermometer. In compressible flow this increment is a constant proportion the free air speed and therefore is of no importance in as far variations in speed-correction coefficient are concerned, ıt at high Mach numbers this is no longer so, as the interrence effects are no longer linear with respect to air speed. t high Mach numbers, also, there is the additional dislvantage of interference from shock waves formed on the ield. Outrigging such as a shield, besides, is always ıpopular with aircraft designers because of the drag it presents, and the turbulence it introduces into the airream ahead of the supporting aerofoil. Flat-plate thermoeters, therefore, must rely on other means of protection om radiation. Protection for the conical head thermoeter was provided by making the outer cover of the mperature element as highly reflecting as possible.

Table 3. *Heat economy and radiation errors of a conical-head thermometer*

ate of heat exchange al × 10^{-3})	Solar altitude (degrees)	*Pressure level* (mb) 100				300				500				900			
		U (miles/h) 200		500		U (miles/h) 200		500		U (miles/h) 200		500		U (miles/h) 200		500	
	h	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33	ε_1 0·15	0·33
	60	2·14	4·70	2·14	4·70	2·07	4·56	2·07	4·56	1·96	4·32	1·96	4·32	1·75	3·85	1·75	3·85
	30	2·10	4·61	2·10	4·61	2·01	4·42	2·01	3·32	1·86	4·08	1·86	4·08	1·62	3·57	1·62	3·57
	60	2·02	4·45	2·02	4·45	2·07	4·56	2·07	4·56	2·17	4·78	2·17	4·78	2·44	5·37	2·44	5·37
	30	1·02	2·25	1·02	2·25	1·05	2·30	1·05	2·30	1·10	2·41	1·10	2·41	1·23	2·71	1·23	2·71
		0·13		0·10		0·11		0·07		0·07		0·02		−0·06		0	
		−0·07		−0·10		−0·09		−0·13		−0·13		−0·18		−0·20		−0·25	
$_5/\Delta T$		5·17		8·18		8·95		14·15		11·46		18·12		15·22		24·07	
$+ Q_2 +$ $Q_3 + Q_4$	60	4·22	9·21	4·16	9·15	4·16	9·14	4·08	9·06	4·07	9·04	3·97	8·94	4·05	8·96	3·94	8·97
	30	3·18	6·92	3·12	6·86	3·08	6·74	3·00	6·66	2·90	6·43	2·80	6·33	2·71	6·02	2·60	6·03
T (°C)	60	0·82	1·78	0·51	1·12	0·46	1·02	0·29	0·64	0·36	0·79	0·22	0·49	0·27	0·59	0·16	0·37
	30	0·62	1·34	0·38	0·84	0·34	0·75	0·21	0·47	0·25	0·56	0·15	0·35	0·18	0·40	0·11	0·25

The outer cover made of a super-pure aluminium base alloy as anodized to give electrical insulation on the inside while ıe outside was given a mechanical polish and afterwards olished electrolytically to give a hard reflecting surface. fter treatment in this manner the absorptivity for visual avelengths is in the region of 0·15. It is not known yet how long the good reflecting properties of the surface will survive exposure in flight, and if it is found that reflectivity decreases considerably during use it may be necessary to renew the outer cover from time to time to maintain a good reflecting surface.

During flight the thermometer will be exposed to solar radiation, both direct and reflected, and also to long-wave radiation from below; it will also lose heat by radiation from itself. The error in temperature from these effects will depend on the rate of heat exchange per degree of temperature difference between the thermometer and the air stream. Some calculations for various pressure heights and at two different air speeds have been made and are given in Table 3. The intensity of solar radiation at the top of the atmosphere was taken as 0·032 cal/cm^2 × s and allowance has been made for attenuation in the atmosphere by the use of a diagram provided by Väisälä.(12) In calculating the effect of the reflected solar radiation, the albedo of the earth's surface has been taken as 0·35, and two solar altitudes have been considered, namely 60 and 30 degrees. The emissivity of the earth's surface for long-wave radiation has been taken as 0·95 after Brewer and Houghton.(13) Absorptivity of the reflecting outer cover of the thermometer for visual radiation was taken as 0·15 but, for comparison, calculations have also been made for an absorptivity of 0·33 which might represent the state of the reflecting surface after some time in use. The emissivity for long-wave radiation (10 μ) was taken as 0·03.

The following formulae and assumptions were used:

(i) Direct solar radiation

$$Q_1 = \varepsilon_1 I_p S_1$$

(ii) Reflected solar radiation

$$Q_2 = K\varepsilon_1 R I_3 \sin \mathrm{h} S_1$$

Allowance was made for loss in reflected radiation by re-transmission from ground level to the thermometer.

(iii) Long-wave radiation exchange with earth

$$Q_3 = B\varepsilon_2(\varepsilon_3\theta_3^4 - \theta_s^4)\frac{S_2}{2}$$

(iv) Long-wave radiation upwards: (downwards radiation from above assumed negligible)

$$Q_4 = B\varepsilon_2(\theta_3^4)\frac{S_2}{2}$$

(v) Rate of heat exchange with air stream: (considering the thermometer as a flat-plate, see Goldstein(14))

$$Q = \frac{0{\cdot}686\sigma^{1/3}kS_2}{l}\left(\frac{U_1 l\rho}{\mu}\right)^{1/2}\Delta T$$

Meaning of symbols used

ε_1 = emissivity of thermometer surface considered as a grey body
ε_2 = ditto for long-wave radiation (10 μ), assumed to be 0·03
ε_3 = emissivity of earth's surface for long-wave radiation, assumed 0·95 after Brewer and Houghton(13)
I_p = intensity of solar radiation at pressure level p in the atmosphere
I_0 = ditto at top of atmosphere (0·032 cal/cm²)
I_3 = ditto at ground level
S_1 = projected area of temperature sensitive surface of thermometer
S_2 = total exposed area of temperature sensitive area of thermometer
σ = Prandtl number
B = Stefan–Boltzmann coefficient, $1{\cdot}37\ 10^{-12}$ cal/cm² $\times A^4 \times S$
θ_s = temperature of the thermometer surface, in degrees absolute (A)
θ_3 = temperature of the earth's surface in degrees absolute (A)
k = coefficient of thermal conductivity
u_1 = air speed in cm/s at the surface of the thermometer
l = length of exposed surface of temperature sensitive surface of thermometer in direction of airstream
μ = coefficient of viscosity of air at thermometer surface
ρ = density of air at thermometer surface
K = shape and orientation factor of thermometer. For horizontal surface $K = 1$, for sphere $L = 2$; as a compromise K was taken as 1·5
R = albedo of the earth's surface, 0·35
h = solar altitude

Pressure levels of 100, 300, 500 and 900 mb and air speeds of 200 and 500 miles/h have been considered.

The following values of air temperature were chosen corresponding to the different pressure levels:

Pressure level (mb)	100	300	500	900
Air temperature (°C)	−57	−44	−21	8

For speeds of 500 miles/h, 24 degrees were added to give the surface temperature of the thermometer, and at 200 miles/h 4 degrees were added.

From Table 3 it is seen that the greatest errors occur at high altitudes where the rate of heat exchange with the air stream is least. To ensure that errors are kept to ½ degree or less a good reflecting surface must be maintained and the fastest speeds used.

MOUNTING FOR THERMOMETER

Whereas a total-head thermometer may be mounted on any forward facing site clear of engine exhaust or induced turbulence, a flat-plate thermometer must be mounted in air stream undisturbed by the aerodynamics of the aeroplane. To obtain absolute independence of aerodynamic influence would require an elaborate platform, which could not be justified for routine measurement work. It is intended, therefore, to mount the thermometer, and supporting string, protruding from the leading edge of a narrow section aerofoil such as a wing or tail.

SUPERSONIC SPEEDS

Although the conical-head thermometer was designed with subsonic speeds in mind, the conical shape is suitable for use in supersonic flow. Taylor and Maccoll(15) showed that for a 20° angle cone in axial supersonic flow, for Mach numbers greater than 1·035, the shock wave is attached at the nose of the cone and the pressure field is uniform over the surface of the cone. It follows, of course, that the velocity field is also uniform over the conical surface. Now the relationship which exists in subsonic flow between the temperature rise on a flat-plate and the square of the local surface air speed has been shown by Eber(16) to hold also in supersonic flow up to Mach number 5 at least.

This means that the formula for the recovery factor in laminar flow, namely,

$$\lambda = 1 - \left(\frac{u_1}{u_0}\right)^2 (1 - \sigma^{1/2}) \quad \text{(see Clark}^{(2)}\text{)}$$

holds at least up to M 5.

Tables for the flow speed along conical surfaces at supersonic speeds have been published by Kopal(17) of the Massachusetts Institute of Technology. Using the values of u_1 obtained from these tables for a 20° angle cone and using the value for $\sigma^{1/2}$ from Clark(2) for 500 mb, namely 0·8466, λ has been calculated for various Mach numbers: the results are given in Table 4.

Table 4. *Recovery factor at supersonic speeds for a 20° angle conical thermometer in axial flow*

u_1/u_c	0·4	0·45	0·50	0·55	0·60	0·65	0·70	0·75	0·80	0·85	0·90
M	1·0902	1·2330	1·4028	1·5957	1·8165	2·0750	2·3869	2·7794	3·3041	4·0748	5·4223
λ	0·8730	0·8675	0·8649	0·8631	0·8616	0·8604	0·8591	0·8580	0·8569	0·8556	0·8543

u_c is the velocity of the air if allowed to expand into a vacuum $u_c^2 = u_0^2\left(1 + \frac{2}{\gamma - 1}\frac{1}{M^2}\right)$, subscript o indicates free stream values.

ACKNOWLEDGEMENTS

In this work I gratefully acknowledge the help given by the staff of the Aerodynamics Division of the National Physical Laboratory during the wind tunnel tests. I also have pleasure in acknowledging the skill of Mr. A. L. Alexander who made the experimental models and the first prototype conical head thermometer and who overcame many difficulties in construction. The paper is published by permission of the Director-General of the Meteorological Office.

REFERENCES

(1) Shellard, H. C. Meteorological Research Papers, No. 527 (London: Air Ministry, 1957).
(2) Clark, D. D. Meteorological Research Papers, No. 677 (London: Air Ministry, 1951).

Brun, E., and **Plan, Max.** *J. Rech. Cent. Nat. Rech. Sci.*, No. 8, p. 231 (1949).
Malmquist, L. *Trans Roy. Inst. Tech., Stockholm*, No. 15 (1948).
Brewer, A. W. *J. Sci. Instrum.*, **24**, p. 47 (1947).
Polhausen, E. *Z. Angew. Math. Mech.*, **1**, p. 120 (1921).
Crocco, L. *Monografie Scien. d. Aeron.* (Rome, December 1946).
Squire, H. B. Reports and Memoranda, No. 1986 (London: Aeronautical Research Committee, 1942).
Dryden, H. L. Report No. 562 (Washington: National Advisory Committee for Aeronautics, 1936).
(10) **Emmons, H. W.** *J. Aeron. Sci.*, **18**, p. 490 (1951).
(11) **Laitone, E. V.** *Quart. Appl. Maths.*, **5**, p. 227 (1947).
(12) **Väisälä, V.** *Geophysics, Helsinki*, **3**, p. 49 (1948).
(13) **Brewer, A. W.**, and **Houghton, J. T.** *Proc. Roy. Soc. A*, **236**, p. 175 (1956).
(14) **Goldstein, S.** (Ed.) *Modern developments in fluid dynamics* (Oxford: Clarendon Press, 1943).
(15) **Taylor, G. I.**, and **Maccoll, J. W.** *Proc. Roy. Soc. A*, **193**, p. 278 (1933).
(16) **Eber, G. R.** *J. Aeron. Sci.*, **19**, p. 1 (1952).
(17) **Kopal, Z.** Massachusetts Institute of Technology, Tech. Rep., No. 1 (1947).

The measurement of the dielectric properties of liquids in an H_{01} resonator

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A simple container which has proved suitable for the measurement of the dielectric properties of liquids in an H_{01} resonator is described, together with a method of correcting for the meniscus.

onvenient method for the measurement of the dielectric perties (relative permittivity and loss factor) of solids at space wavelengths in the region of 1 and 3 cm makes of a cylindrical resonant cavity operating in the H_{01} de.(1,2) The samples take the form of thin disks resting a movable piston which forms one end of the resonator. use this method for the measurement of liquids requires ne form of cup to hold the liquid. Two sources of error e, the first from distortions in the electric field brought ut by the presence of the cup and the second from the sence of a meniscus on the surface of the liquid.

he only cup which is reported to have been used is a tal one(3) which leads to errors of 5–10% in relative mittivity.(3,4) That these errors do not arise only from presence of a meniscus was shown by measuring some d specimens with and without a metal cup.(4) The errors loss factor are harder to assess, but they are believed to as high as 10% in some instances.(4)

he electric field E falls to low values near the walls and a layer of dielectric placed there should have little effect. is suggests that a container with dielectric walls and a tal base should be satisfactory. Measurements have been ried out in this Laboratory using a silica cup with thin lls and with a flat metal disk resting on the bottom, the surface of the disk and the bottom of the cup being allel (Fig. 1).

he energy stored in the sample is proportional to the ume integral of the square of the electric field. On the umption that the electric field is constant in the axial ection over the region occupied by the meniscus it is ssible to obtain the thickness t of a disk equivalent to the niscus (see Appendix).

$$t = \frac{\int_0^a J_1^2(3\cdot 83r/a)rh(r)dr}{\int_0^a J_1^2(3\cdot 83r/a)r\,dr}$$

this thickness t is added to the centre thickness then the complex permittivity can be calculated by the usual method.(2) The function $rJ_1^2(3\cdot 83r/a)$ is plotted in Fig. 2 as curve (*b*). The cross-section of the liquid surface (for decalin), as measured, is shown in Fig. 2(*a*) and curve (*c*) is obtained by multiplying the value of $rJ_1^2(3\cdot 83r/a)$ by the height (in mm) by which the liquid surface exceeds that at the centre. The ratio between the area under curve (*c*) and that under curve,

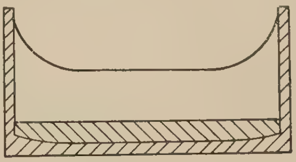

Fig. 1. Cup for holding liquid

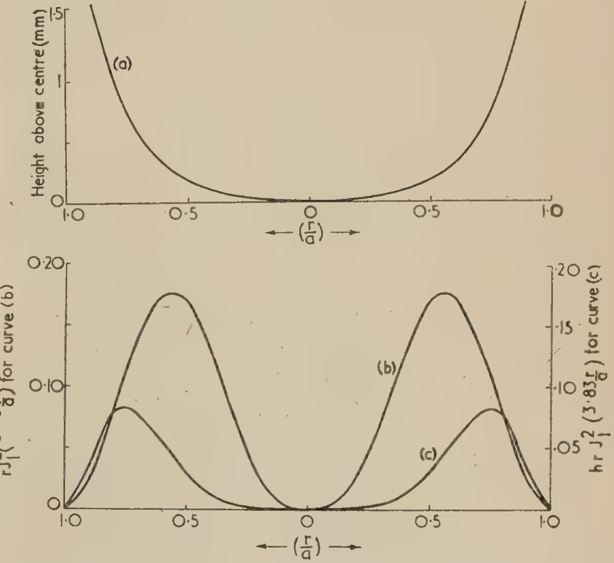

Fig. 2. (*a*) Surface of liquid. (*b*) Plot of $rJ_1^2(3\cdot 83r/a)$. (*c*) Product of liquid height above centre and $rJ_1^2(3\cdot 83r/a)$

(*b*) is the thickness in mms which is added to the centre thickness to give the equivalent disk with both surfaces plane.

The errors in this calculation will be least when the meniscus lies in a region where the variation in the electric field along the axis of the resonator is a minimum. Since this is a sine function there is a broad region about a quarter wavelength, three-quarter wavelength, etc., where this condition is approximately fulfilled. For a sample of the hydrocarbon decalin ($C_{10}H_{18}$) with centre thickness $0{\cdot}28\,\lambda_g$, in which the thickness correction is 11%, the difference between ϵ' measured at 1·25 cm wavelength in the cup shown and calculated in this manner, and that measured at lower frequencies was 1%. Errors in ϵ'' are harder to assess, but values measured by this method for dilute solutions of a polar solute in decalin and other non-polar solvents lie on a Debye curve drawn through points measured at lower frequencies. In addition, a Perspex sample, with the top surface cut to approximate to a meniscus, was measured and ϵ'' agreed to within 2% of that measured on a normal disk sample cut from the same rod.

APPENDIX

Let $h(r)$ be the height of the meniscus at radius r above the level top surface, and $E(r)$ the value of electric field at same radius. Volume of meniscus slice of thickness dr equals $2h(r)rdr$. From perturbation theory, one has

$$\left(\frac{\Delta\omega}{\omega}\right)_{meniscus} = \frac{\epsilon\int_0^a |E(r)|^2 2\pi rh(r)dr}{2W} \qquad (1)$$

where ϵ = permittivity of specimen
W = total stored energy in cavity
a = radius of cavity.

If t be the thickness of disk equivalent to the menisc
then the perturbation will be given by

$$\left(\frac{\Delta\omega}{\omega}\right)_{disk} = \frac{\epsilon\int_0^a |E(r)|^2 2\pi rt\,.\,dr}{2W}$$

Since these perturbations are to be equal, one obtains

$$t = \frac{\int_0^a |E(r)^2 rh(r)dr}{\int_0^a |E(r)|^2 rdr}$$

which for an H_{01}-mode resonator becomes

$$t = \frac{\int_0^a J_1^2(3{\cdot}83r/a)rh(r)dr}{\int_0^a J_1^2(3{\cdot}83r/a)rdr}$$

REFERENCES

(1) Bleaney, B., Loubser, J. H. N., and Penrose, P. *Proc. Phys. Soc.* [*London*], **59**, p. 185 (1947).

(2) Horner, F., Taylor, T. A., Dunsmuir, R., Lamb, and Jackson, W. *J. Instn Elect. Engrs*, **93**(III), p (1946).

(3) Powles, J. G., and Jackson, W. *Trans Faraday So* **42A**, p. 101 (1946).

(4) Dryden, J. S. Ph.D. Thesis (University of Lond 1950).

A self-adjusting unit for the control of an animal calorimeter

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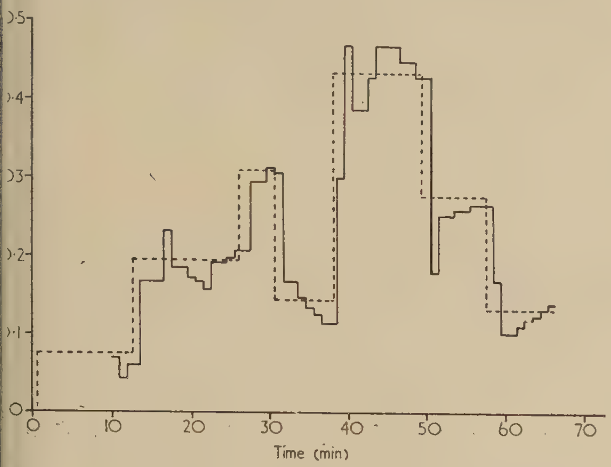
A unit is described which automatically adjusts the value of a continuous current passing through a coil placed in a chamber so that the rate of heat dissipation duplicates that released by a small animal in a similar chamber.

The direct determination of the heat output of mice in any particular state of activity is complicated by the fact that the animal, in general, does not stay in that state for more than a few minutes. The differential calorimeter described by Clarke and Hawkins(1) overcomes this difficulty to a large extent by virtue of the low thermal capacity of its chambers. In this calorimeter the wattage dissipated by an electric heating coil is adjusted so that the wall temperature of the chamber containing the coil is the same as the wall temperature of a similar chamber containing the animal. The heat output of the animal is then known in terms of the watts dissipated in the coil. This process is illustrated in Fig. 1 which shows the result of a test of the original calorimeter. A second heating coil replaced the animal and the wattage dissipated in it was varied in a manner unknown to the operator of the calorimeter. Although the heating pattern used in this test gave greater changes in the heat output than are actually obtained from the animal, it will be seen that the pattern was duplicated by the operator with a fair degree of fidelity.

The control unit described below has been designed replace the operator so that the calorimeter can be used times when an operator is not available. It will be realiz that standard methods of obtaining temperature equal between the two chambers, such as the use of a.c.-energiz gas-filled valves, would not give a heat output pattern w the same levels as the original; they would give an avera heat output equal to that of the animal over a period of tim What is required, however, is the heat output of the anim when it is still, when it is washing, etc. For this reason t apparatus is more complicated than at first appears necessa The apparatus is not claimed to be ideal; being se mechanical it has a response time far longer than is desir but no non-mechanical solution has so far been devised what appears to be a new problem in this field.

The control unit must retain control whatever the anim does. Moreover, experience with the manual apparatus h shown that the temperature difference between the chamb must not rise above 0·5° C otherwise, due to the therm capacity of the chambers, corrections to the rate of heati e to be so large that "hunting" occurs and a useful record ot obtained. These difficulties have been overcome in following ways.

he first is that the control unit only adjusts part of the trical energy, two heating coils being used. One coil is plied at an energy level below the lowest value expected n the animal; the other coil is controlled by the unit cribed. The second is that the unit carries out adjustnts to the watts dissipated at a rate determined by the ent of the temperature difference existing between the mbers.



g. 1. Energy dissipated in two chambers plotted against time

– – – animal; ——— manually controlled.

With a control unit automatically adjusting the heat output a coil to equal the heat output of an animal, a calibrated ording milliammeter in the heating circuit gives a continuous record of the heat output of the animal. The state of activity of the animal can also be recorded on the second pen of a Duplex recorder (by Everett, Edgcumbe & Co. Ltd.) by the carbon granule technique described by Clarke and Hawkins.$^{(2)}$

DETAILS OF THE APPARATUS

Copper-constantan thermo-junctions are in thermal contact with the walls of the two chambers of the calorimeter and are connected differentially to a reflecting galvanometer and resistance in series. The arrangement is indicated in Fig. 2.

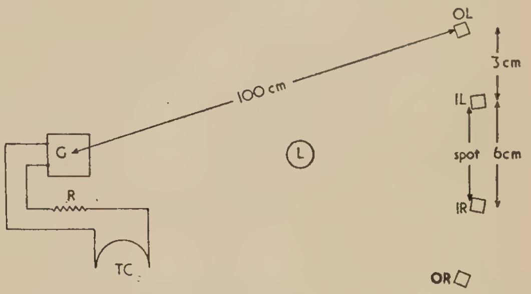


Fig. 2. The arrangement of the galvanometer and the photoconductive cells

G = galvanometer type 10 D (by H. Tinsley and Co. Ltd.), 50 Ω, 300 mm/µA.

IL, IR, OL, OR = photoconductive cells type FT 423 (by Hilger and Watts Ltd.).

L = support for galvanometer lamp, 12 V, 36 W.

R = 20 Ω

TC = copper-constantan thermocouple.

The light beam reflected from the galvanometer falls between the two inner photoconductive cells when there is temperature equality.

When the temperatures are different the spot may fall on (i) an inner cell (0·02 – 0·1° C temperature difference), (ii) both an inner and an outer cell (0·1 – 0·2° C), or

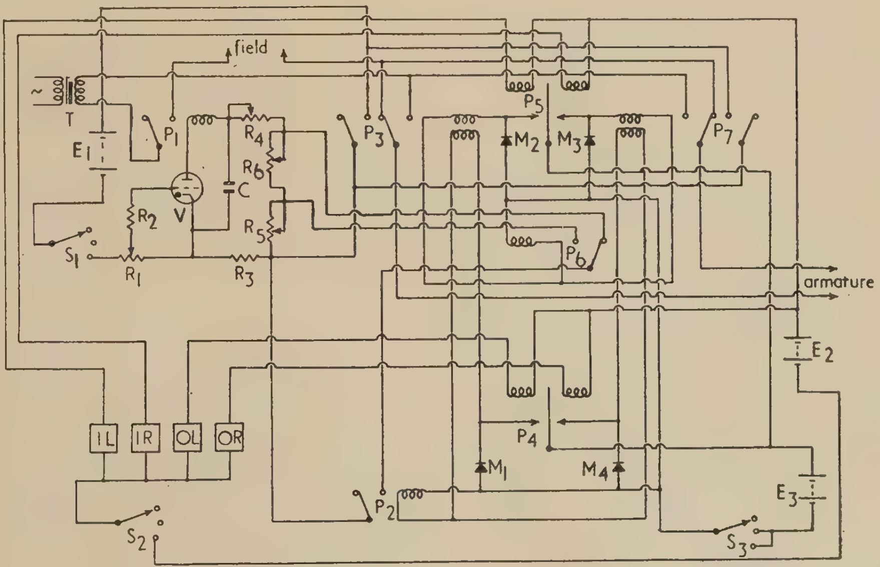


Fig. 3. Circuit diagram of control unit

nature/field = Meccano motor type E 20 R.
C = 2 µF
E_1 = 120 V dry battery
E_2 = 3 V dry battery
E_3 = 6 V rectified a.c.
IR, OL, OR = cells type FT 423 (by Hilger and Watts Ltd.)
M_1, M_2, M_3, M_4 = instrument rectifiers 12 V, 5 mA
P_1, P_3, P_7 = relays type 100, 160 Ω + 160 Ω (by Siemens Edison Swan Ltd.)
P_2, P_6 = relays type 88, 50 Ω + 50 Ω (by Siemens Edison Swan Ltd.)
P_4, P_5 = moving coil relays type R 350 B, 350 Ω [by Elliott Bros. (London) Ltd.]
R_1 = 15 kΩ
R_2 = 47 kΩ
R_3 = 285 kΩ
R_4 = 0·5 MΩ
R_5 = 0·5 MΩ
R_6 = 0·5 MΩ
$S_1/S_2/S_3$ = 4-pole, 3-way
T = Meccano transformer type T20M
V = argon-filled thyratron type GT1C

(iii) an outer cell only (0·2 – 0·4° C). The optimum value for the resistor was found experimentally by trial and error as were the positions of the cells. They are so arranged that the spot does not leave the outer cell (which could cause the unit to lose control) whatever changes of activity occur when an albino mouse is used as the experimental animal.

For simplicity the control circuit (Fig. 3) is shown as battery operated. In practice, the gas-filled triode and photo-cells are energized by dry batteries and the relays energized by rectified a.c.

The circuit is most easily understood by considering its operation when the temperature of the animal chamber rises rapidly above that of the heater chamber as, for example, when an animal awakens and begins to wash. As the light spot falls on the inner right-hand cell, the moving coil relay P_5 closes to the right. This relay in turn closes P_6, but this has no effect as P_2 is open. The double changeover action relay P_7 is closed at the same time. The left-hand tongue of P_7, in combination with with right-hand tongue of P_3, acts as a reversing switch for a small electric motor mechanically coupled to a potential divider controlling the watts dissipated in the heater chamber. The direction of rotation with P_7 closed produces an increase in the heating current. The right-hand tongue of P_7 connects the battery E_1 to a gas-filled triode relaxation oscillator and the heating current begins to increase in steps. The oscillator pulses, from the discharge of the capacitor C, pass through the coil of relay P_1, the tongue of which is in the supply line to the motor. Thus, so long as the light spot is on the inner cell, a series of pulses pass through the motor. The motor has a 100 : 1 step down gear and worm train connected to a helical, three-turn potential divider. The wiper of the potential divider is, therefore, rotated in very small increments.

With a rapid increase in heat output the light spot will travel outwards until it covers both the inner and outer cells. P_4 closes to the right with the result that: (i) P_2 closes, and (ii) current passes through the second coil of P_7. It will be recalled that P_6 was closed as soon as P_5 closed, but with no effect since P_2 was then open. With the closure of P_2 it will be seen that the resistor R_5 is short-circuited. The frequency of the oscillator is thus increased, with the result that the number of correcting impulses per minute is increased.

If the light spot moves so far over as to leave the inner cell and only illuminates the outer cell, P_5 opens and therefore P_6 is released. P_7 remains closed due to the current through its second coil. With P_6 open and P_2 closed, the resistor R_6 is short circuited as well as R_5, thus the number of correcting impulses per minute is further increased. The temperature of the heating chamber is now rising. The spot returns back towards the centre and the processes go into reverse, the number of corrections per minute decreasing the nearer to equality the temperatures become. This reduces overshooting to an acceptable degree. Galvanometer deflexions in the opposite sense produce the same sequence of events except that P_3 closes instead of P_7 so that the corrections are in the opposite sense, the motor rotating in steps to reduce the heating current.

ADJUSTMENTS

The oscillator frequencies are best adjusted from high to low. With the outer photocell illuminated, R_4 is adjusted; with two cells illuminated, R_6 is adjusted and, with the inner cell alone illuminated, R_5 is adjusted. R_1 adjusts the bias and is a useful coarse adjustment. With albino mice as the experimental animals the frequencies in use are approximately 50, 65 and 80 pulses/min. Two further sets of adjus ments are: (*a*) the value of the resistor in the galvanomet circuit, and (*b*) the positions of the photocells. These a not critical, but the values given in Fig. 2 have been foun suitable for mice repeating their normal pattern of washin still, sleeping, washing, still, etc.

When the apparatus is in use, the control unit is switche to the stand-by position (i.e. the filament of the gas-fille triode is put into circuit) and the heat outputs brought int approximate balance by manual operation of the gear trai connected to the potential divider. The control unit is the switched to the operating position. This procedure ensur that the unit is actually in control.

TESTS OF THE APPARATUS

The ability of the control unit to follow variations of he output was tested by inserting into the animal chamber a electric heating coil and varying the wattage dissipated in pre-arranged manner. The "programmes" were based o the very large number of records for albino mice which hav been obtained with the manually operated calorimeter. The watts dissipated by the coils in the controlled chamb were noted at half-minute intervals. A typical record given in Fig. 4, the "animal" figures being those of a 38 mouse. It will be seen that the apparatus has produced smoothed version of the original pattern with a time lag of few minutes. The upper and lower levels are given withi ±2% and the total energy dissipation in the two chambe in the 27 min is the same within ±1%.

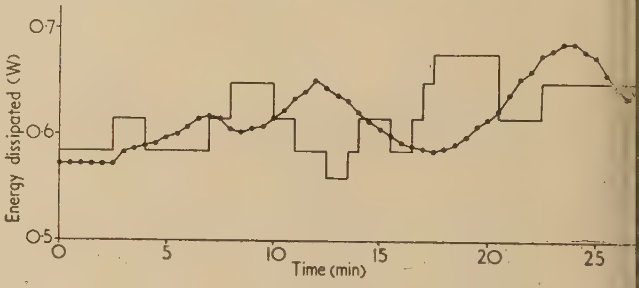


Fig. 4. Energy dissipated in two chambers plotted against time

——— animal; -●-●-●- automatically controlled.

CONCLUSION

It has been shown that the control unit will produc variations in heat output in a chamber which duplicat variations in another chamber. As already mentioned would be advantageous to have a shorter response time s that the accuracy of the replica was improved, but it must remembered that such accuracy is often illusory whe working with animals. For example, normal albino mice the same weight and sex have different behaviour patter and thus produce heat at different rates when in the sam apparent state. The following values (in kilocalories day^{-} have been obtained for 25 g albino mice in a still state:

Male 10·0, 9·6, 9·9, 10·1, 9·9, 10·2, 9·8, 9·6. Average: 9·

Female 9·9, 9·7, 9·8, 9·5, 9·9, 9·7. Average: 9·8

These figures are the averages of approximately twenty-fiv dings obtained during 30 min with the mouse in the nual apparatus, and the control unit is thus reasonably sfactory since it duplicates heat outputs to within ±3% ch is sufficiently accurate for this work.

ACKNOWLEDGEMENTS

he author is indebted to Professor E. C. Amoroso for interest and encouragement in this work and to Dr. G. C. Clarke for the idea of using two heating coils. The author also wishes to thank Miss G. Tomlinson and Mr. J. Gunner for technical assistance.

REFERENCES

(1) Clarke, E. G. C., and Hawkins, A. E. *Phys. in Med. Bio.*, **1**, p. 118 (1956).
(2) Clarke, E. G. C., and Hawkins, A. E. *Nature* [*London*], **179**, p. 1361 (1957).
(3) Clarke, E. G. C., and Hawkins, A. E. *Nature* [*London*], **181**, p. 1599 (1958).

A thermocouple method for measuring relative humidity in the range 95–100%

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At high relative humidities a current of 30 mA through a 38 s.w.g. chromel-*p*/constantan thermocouple produces sufficient Peltier cooling to form a film of water on the junction which may then be used as the wet-bulb of a psychrometer. The wet-bulb depression can be read to 0·001° C and in the range 97–100% changes of 0·01% relative humidity can be detected.

After calibration over sodium chloride solutions the psychrometer has been used to determine the water content/free energy curves of two soils, and good agreement has been obtained with previous determinations by other methods.

the many methods available for the determination of the ative humidity of air, the measurement of wet- and dry-lb temperatures with a psychrometer is one of the most satile, for many different types of thermometer may be d and also the psychrometer formula is reliable over a de range of temperatures and humidities. Within a few cent of saturation it demands the precise determination a very small temperature difference: e.g. the wet-bulb pression of air at 25° C and 99% r.h. is only 0·13° C. In closed system the temperature must be constant and uni-m because even small variations can lead to condensation, d the apparent relative humidity may then vary both with position of the psychrometer and with time. Temperature ntrol is achieved most easily when the volume of air is all, but evaporation from the wet-bulb may then increase relative humidity that it is required to measure. These ficulties are not insuperable and the paper describes a nple apparatus which has been used to measure relative midity in the range 95–100%, and hence to determine the motic potential of salt solutions and the water potential a porous medium such as soil.

The present technique is a development of a method ploiting the Peltier effect devised by Spanner(1) to whose per reference may be made for basic principles. Spanner ed a junction of fine wires of bismuth and a bismuth-tin oy, cooled it by a suitable current until condensation curred and then connected it to a ballistic galvanometer, throw of which was a measure of the dew-point temrature of the air around the junction. Temperature control s maintained to ±0·0004° C. At Rothamsted, P. B. Flegg the Glasshouse Crops Research Station, had some success modifying Spanner's technique,(2) and since then most of technical difficulties have been overcome. The main modifications that have been made to Spanner's method are: (i) the fine bismuth and bismuth-tin wires, which are fragile and which cannot be obtained commercially, have been replaced by constantan and chromel of 38 s.w.g. The consequent reduction of sensitivity has been found unimportant in practice; (ii) instead of a ballistic throw, which is a function of dew-point temperature, a steady wet-bulb depression is obtained. This can be more easily read and can be related to a theoretical value.

THERMOCOUPLE SYSTEM

The Peltier element is mounted on a rubber bung that will fit a standard specimen tube 2·5 × 7·5 cm (Fig. 1). The external leads, brought through the bung, project about 5 mm and to their ends are soldered lengths of 38 s.w.g. chromel-*p* and constantan wire. In assembly, these wires are crossed at 8 mm, the cross-over soldered, and the surplus cut off with a razor blade. The soldered junctions are immersed in boiling water for five minutes to remove all traces of flux, and are then inspected under a low-power microscope to ensure that the joints are clean and well made. By trial it has been found that the best solder is a 60 parts tin: 40 parts lead, with zinc chloride used as flux.

To provide a constant temperature sink for the Peltier heating of the other junctions, and for the Joule heating in the thermocouple wires, the copper leads pass through short lengths of drilled copper rod, 6 mm external diameter, mounted in the bung. In effect these rods form the "dry-bulb" of the psychrometer, and the galvanometer system measures the temperature difference between the rods and the chromel/constantan junction. The sensitivity of the thermocouple has been found to be 62·5 μV/° C, the lamp and scale galvanometer sensitivity (type 4500 by Tinsley) is 167 mm/μA at 1 m, and with a total circuit resistance of

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11·3 Ω the thermometer scale is 92·5 cm/° C. Test of the zero, with the specimen tubes in the constant temperature bath (next section) show no short term deviation greater than $\frac{1}{2}$ mm, indicating that fluctuations in ambient temperature in the tubes are not greater than $\pm 5 \times 10^{-4}$ ° C.

For cooling the junction, a current of 30 mA, passing from the constantan to the chromel wire, is provided by a rectifier working from a.c. mains. This choice of current, and that of 8 mm for the length of the wires, is based on experiments at one humidity (Fig. 2).

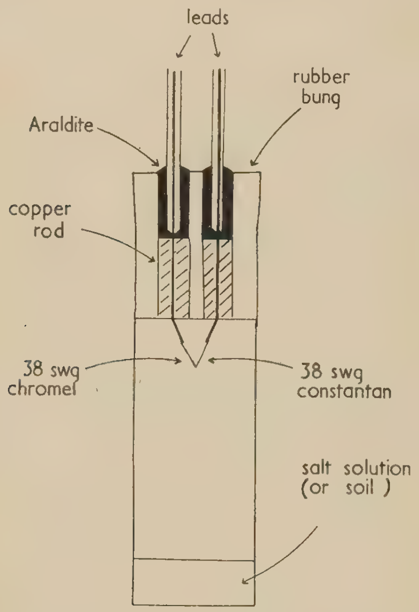

Fig. 1. Thermocouple mounted on rubber bung fitting 2·5 × 7·5 cm glass specimen tube

Leads are 20 s.w.g. copper with polyvinylchloride insulation.

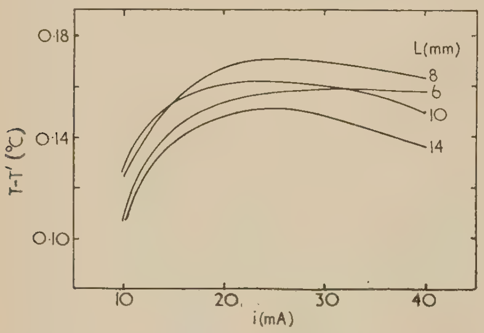

Fig. 2. Wet-bulb depression $T - T'$ thirty seconds after passage of cooling current as function of cooling current i and of couple length L

Optimum current 25–30 mA; optimum length 8 mm. (Relative humidity 98·4%.)

A bank of suitable two-pole switches makes it possible to pass the cooling current through any chosen junction and then to switch this junction into the galvanometer circuit.

CONSTANT TEMPERATURE BATH

The space above the copper rods is made watertight by an Araldite seal (Fig. 1), and the tubes can be completely immersed in the constant temperature bath. This is a 2½ gallon polythene cistern, lagged with glass fibre, with mercur and toluene regulator, Sunvic proportioning head an electronic relay to control a 50 W immersion heater. Th stirrer motor also provides gentle agitation for the mercur in the regulator. There are 20 cm of water in the cister and the top is kept open to the air in the belief that evapora tion acts as a buffer against the unavoidable fluctuations i room air temperature: replacements of water, at the correc temperature, are made as required. After 5000 hours o continuous running this bath still shows no visible change i the reading of a Beckmann thermometer over periods o twenty to thirty minutes, and hour-to-hour changes ar only of the order of $\pm 10^{-3}$ ° C. As a further precaution t prevent heat exchange, the connecting wires to the tubes ar coiled so that the first 25 cm of their length are under wate

CALIBRATION

The classical formula relating vapour pressure e to we and dry-bulb temperatures T' and T may be written

$$e = e_{s'} - Ap(T - T')$$

where $e_{s'}$ is the saturation vapour pressure at T', p is th atmospheric pressure and A is the psychrometer "constant. The precise value of A depends on the relative importance o terms in the heat exchange of the wet-bulb which, in tu depend on such factors as the size of the bulb, the conducti of heat from supports and the rate of ventilation. For normal aspirated thermocouple $A \simeq 6{\cdot}2 \times 10^{-4}$ ° C^{-1}, but for a thermocouple in still air A exceeds this value by a amount which cannot be estimated *a priori* with an confidence.

Calibration of the thermocouple therefore takes the for of measuring T–T' at fixed T in atmospheres of know relative humidity. When $T \simeq T'$

$$e \simeq e_s - (\delta e/\delta T + Ap)(T - T')$$

Relative humidity r is then

$$r = e/e_s = 1 - [(\delta e/\delta T + Ap)(T - T')/e_s]$$

so that the relation between thermocouple output ar relative humidity should be linear for constant A. Atmo spheres of known relative humidity can be provided b sodium chloride solutions using unpublished data by G. F Cashen in the range 0·1–2·0 M.(4) With bismuth/bismuth–ti couples, Flegg found the anticipated linear relation betwee relative humidity and wet-bulb depression between 97 ar 100% r.h., varying with temperature between 10 and 25° C as predicted by equation (3). A small wet-bulb depression observed even at $r = 1{\cdot}00$ (distilled water) and this is attr butable to the slight desiccation of the air immediatel around the wet-bulb when water condenses on it. With th chromel-constantan couples, there is a small deviation fro linearity over this range which can be attributed to dependence of amount of deposit on relative humidity.

To obtain a calibration, a small quantity of standar sodium chloride solution is placed in a specimen tube (Fig. 1 the walls of which may be lined with filter paper to assi rapid equilibration. The thermocouple unit is first gentl heated for four or five minutes over a 100 W bulb, befor being inserted in the tube to drive off moisture and to avoi condensation on bung or couple when the system is place in the constant temperature bath at 25° C. A short length o fine string is inserted with the bung and is then withdraw thus ensuring that atmospheric pressure is obtained withi e tube. The tubes, clipped to a metal stand, are immersed the bath and left to equilibrate, taking about six hours if a ter paper lining is used. Before passing a cooling current rough the couple the Peltier junction is switched into the lvanometer circuit and the scale is set to zero. The ference between this setting and the mechanical zero is a easure of spurious voltages in the circuit and is seldom eater than 0·2 μV. Exceptional larger differences have en traced to poor temperature control, or to sunlight lling on the galvanometer or switches.

A current of 30 mA is then passed through a selected uple for one minute, after which the couple is thrown back to the galvanometer circuit and the wet-bulb temperature bserved after a further minute. This procedure is repeated r each couple in turn and for solutions of different con-ntration to obtain a calibration curve of the type shown in g. 3. Scrupulous care must be taken to ensure that the ngs do not become contaminated with salt solution and at the tubes are watertight.

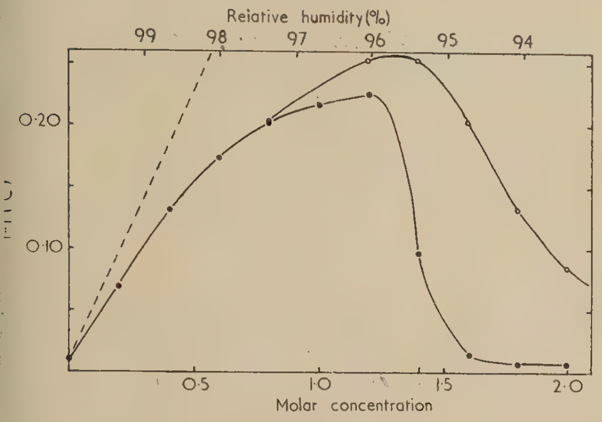

Fig. 3. Calibration of typical thermocouple at 25° C

•——• = wet-bulb depression $T - T'$ observed sixty seconds after cooling current is cut off.
○——○ = maximum depression.
- - - - - = response of fully ventilated thermocouple psychrometer.

The apparent variation of the wet-bulb depression with ne is a function of relative humidity. Between 100 and 97% the observed depression is a maximum after sixty seconds and remains virtually constant for about ten seconds. From 97–96% the maximum depression is reached at about forty to fifty seconds and by sixty seconds the depression is slowly decreasing. From 96–95% the depression decreases very rapidly after thirty seconds. This behaviour can be related to the length of wire on which condensation occurs. Above 96% the amount of condensation is sufficient to provide an adequate water reserve for a minute after the cooling current stops, but below 96% most of the water evaporates within this time. The difference between the two types of curve is shown in Fig. 4, and observation of the rate of change of wet-bulb depression eliminates possible confusion between the two humidity values which give the same deflexion after sixty seconds.

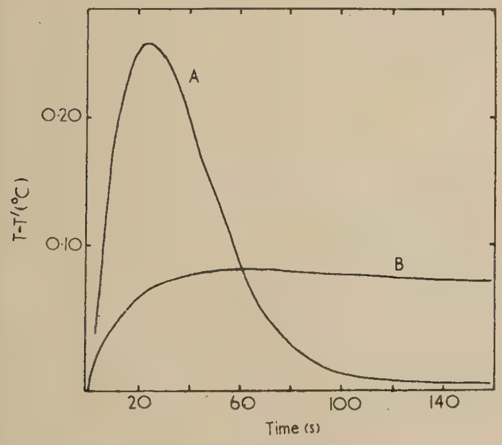

Fig. 4. Variation of wet-bulb depression $T - T'$ with time after passage of cooling current

Curve A, 95·4% r.h.; curve B, 99·1% r.h.

Whatever the relative humidity, the depression begins to decrease rapidly as the last traces of water evaporate from the junction. The time elapsing before this rapid change has been found to be directly proportional to the time for which the cooling current is passed, and is therefore determined by the *amount* of condensation. But since the *length* of wetted wire which determines the efficiency of the wet-bulb is relatively unaffected by an increase in cooling beyond sixty seconds, little gain in sensitivity can be achieved by longer cooling. The range can be extended to about 93% r.h. by taking the maximum depression instead of the depression after sixty seconds (Fig. 3).

OPERATION

When the couples have been calibrated they can be used to measure the equilibrium relative humidity, and hence the osmotic potential, of any other solution within the range of the instrument. Occasional re-calibration is advisable but changes in sensitivity from month to month seldom exceed a few per cent. Gross changes in sensitivity are rare and can always be traced to the failure of a soldered joint.

The main use to which the apparatus has so far been put is the measurement of the (negative) free energy of soil moisture, an important quantity both for the soil physicist studying the flow of moisture in unsaturated soils and for the plant physiologist concerned with the availability of water to plant roots. The free energy of soil moisture has two components. The first is a consequence of surface tension acting in the soil capillaries and is important in all soils; the second is a consequence of the presence of dissolved salts, and while rarely important in agricultural soils may be very important in horticultural practice. The fundamental unit for free energy is ergs per gramme, but it is more convenient here to work in terms of a potential energy expressed in metres of water, a unit which is related to equilibrium relative humidity by the formula

$$d = (RT/100\,gM)(-\ln r) \tag{4}$$

where d = moisture potential in m of water,
$R = 8\cdot314 \times 10^7$ ergs°C^{-1} mol.$^{-1}$,
T = absolute temperature,
$g = 981$ cm^2/s,
M = molecular weight of water $= 18\cdot02$.

As r is always very close to unity

$$d \simeq (RT/100\,gM)(1 - r) \tag{5}$$

If r is expressed as a percentage ($r = U/100$)

then $d \simeq 140(100 - U)$ at 25° C.

Note that $\log_{10}(100\,d)$ is the equivalent of Schofield's pF.$^{(5)}$

Since between 100 and 97% a scale division of 1 mm corresponds to 0·01% r.h., the reading error in this range is about 1·4 m. Very close to saturation, however, minute temperature fluctuations can produce condensation within the sample tube and wet-bulb depressions tend to be erratic. The upper limit of the instrument is therefore about 99·98% or 3 m.

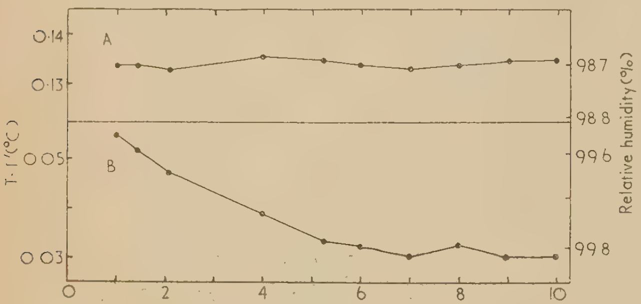

Fig. 5. Change in relative humidity with time over two samples of the same soil at different moisture contents

Curve *A*, 10·5%; curve *B*, 16·6% moisture on dry weight basis.

Readings can be obtained down to about 95% r.h. or 700 m, but beyond 97% the wet-bulb depression changes rapidly with time, and errors of the order of 10 m may arise from the difficulty of obtaining an accurate galvanometer deflexion. On the *pF* scale the useful range of the instrument is therefore about 2·5–4·8.

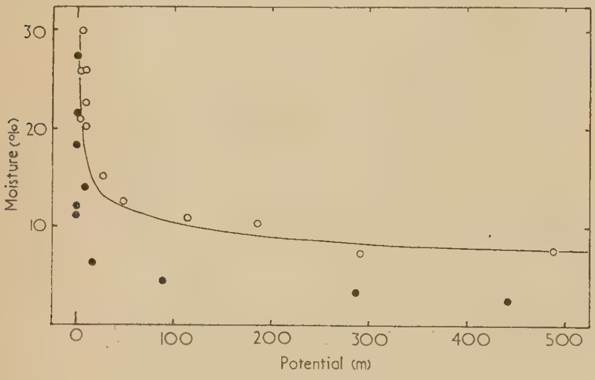

Fig. 6. Water potential in metres as a function of soil moisture content (% dry weight)

● = Woburn sandy loam.
○ = Rothamsted clay loam.

The full line was obtained by Schofield$^{(5)}$ for Rothamsted Grass Plots.

To obtain the moisture potential of a drying soil as a function of its moisture content, a sample of 100 g of the soil is oven dried at 105° C, and then wetted on a sintered glass plate against a suction of about 10 cm water ($d = 0 \cdot 1$ m). About 4 or 5 g of the wetted soil are then placed in each of six sample tubes and allowed to dry out for different times to obtain a pre-determined range of moisture contents. The tubes are then corked with the thermocouple units an placed in the bath. Moisture equilibration of the soil wit the air in the sample tube generally takes about a week.

Equilibration takes longer with wetter than with drie soils, probably because gradients of moisture potential an hence of vapour pressure are smaller in wet than in dry soils Fig. 5 shows two typical equilibration curves. Equilibratio has been found to be more rapid and the final wet-bul depression more constant with soils which have stood i the laboratory for several months in an air-dry state tha for soils which have been used immediately after bringing i from the field. One possible explanation is that microbia action in the fresh soil may alter the osmotic component c the moisture potential.

The moisture potential curve for a soil with 25% cla content (Rothamsted clay loam) and a soil with 10% cla content (Woburn sandy loam) are shown in Fig. 6. Th full line was obtained by Schofield$^{(5)}$ for similar Rothamste soil from determination of the freezing-point depression an by centrifuging, and agreement with the points determined b equilibrium r.h. is close.

CONCLUSION

The care needed in assembly, and the close control temperature needed in calibration and use limit this techni to that of a laboratory tool for use in research. Like freezing-point method, and in common with other vapou pressure techniques, it gives (indirectly) a measure of total free energy decrease of water in a porous system, ma up of capillary and osmotic effects. The disadvantage o long delay in reaching equilibrium near saturation (abou week) is more than compensated by the ability to determi many points on the water content/potential curve simu taneously. In the end, a complete curve may be obtaine more quickly in this way than by any other technique c combination of techniques under routine conditions tha demand no special skills.

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REFERENCES

(1) Spanner, D. C. *J. Exp. Bot.*, **2**, p. 145 (1951).
(2) *Rothamsted Experimental Station Report*, Harpende note on p. 40 (1955).
(3) Monteith, J. L. *Proc. Phys. Soc.* [*London*] *B*, **67**, p. 21 (1954).
(4) Owen, P. C. *J. Exp. Bot.*, **3**, p. 188 (1952).
(5) Schofield, R. K. *Trans 3rd Int. Congress Soil Sci.*, p. 37 (1935).

A simple orbit contractor for betatron-started synchrotrons

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The contractor uses a small thyratron to control the current in a coil around the betatron flux of the machine, the current being supplied by the changing betatron flux. The X-ray yield is increased by a factor varying from three to twenty.

e of the main problems in circular electron accelerators is t of injecting electrons into stable orbits without sub-uently intercepting a large fraction of these electrons by electron gun structure. Several different methods of proving injection efficiency have been suggested,(1–6) and purpose of the present paper is to describe in some detail design of an orbit contractor which has been in successful eration for two years on the Oxford 125 MeV electron ıchrotron.

THEORY OF THE METHOD

The radius of instantaneous circular orbits in a betatron given by the condition(7)

$$\beta(r, t) \equiv \Phi(r, t) - 2\pi r^2 B(r, t) = \text{constant} \qquad (1)$$

ere $\Phi(r, t)$ is the flux through and $B(r, t)$ the induction on ircle of radius r at time t. Unless flux biasing is used, the ıction $\beta(r, t)$ is zero at the equilibrium orbit $r = r_0$ and creases with increasing radius within the stable region. $|\beta(r, t)|$ at a fixed radius increases with time during the celerating period, the instantaneous circles move towards equilibrium orbit in order to maintain the condition own in equation (1).

One method of improving injection efficiency is to displace instantaneous circles away from the gun during the injec-n period as suggested by Adams.(1) With external injec-n, that is with the gun at a radius greater than r_0, this plies decreasing $\beta(r, t)$ [not $|\beta(r, t)|$] at any fixed radius ring injection. Some decrease in $\beta(r, t)$ is produced by circulating electron beam itself, and the contraction during build-up of circulating current is one of the capture chanisms suggested by Kerst.(8)

Contraction of instantaneous orbits may also be produced passing a current through a coil linking the betatron x,(6) as shown in Fig. 1. If this current flows in the posite sense to that in the main exciting coil of the magnet, betatron flux is reduced by an amount Φ_c (subsequently referred to as the contractor flux), and, since the main exciting coil acts substantially as a constant flux generator, there is a corresponding increase Φ_c in the guide field flux. Thus $\Phi(r, t)$ is reduced and $B(r, t)$ increased, and the two effects co-operate in reducing $\beta(r, t)$.

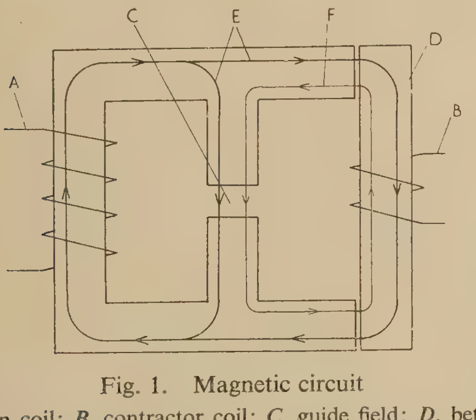

Fig. 1. Magnetic circuit

A, main coil; *B*, contractor coil; *C*, guide field; *D*, betatron bars; *E*, flux from main coil; *F*, contractor flux Φ_c.

A current flows in the appropriate sense if the ends of the contractor coil are simply connected by a resistor, as the changing betatron flux induces an e.m.f. tending to oppose the change. This means that, if the induced e.m.f. is large enough, the contractor may be self-energized. It will be shown in the next section that, for the Oxford machine, this condition is fulfilled.

The change in $\beta(r_2, t)$ necessary to displace instantaneous circles to r_2 from some other radius r_1 may easily be calculated from the radial variation of magnetic induction by the relation

$$\Delta\beta(r_2, t) = \beta(r_1, t) - \beta(r_2, t) = \\ = \int_{r_1}^{r_2} 2\pi r(B + r\partial B/\partial r)dr \qquad (2)$$

In order to estimate the change in $\beta(r, t)$ produced by applying instantaneously a given contractor flux Φ_c it is convenient to express $\beta(r, t)$ in the form

$$\beta(r, t) = \Phi_b(t) - \alpha(r)\Phi_g(t) \qquad (3)$$

where Φ_b is the total flux carried by the betatron bars and Φ_g is the total flux in the guide field. Then, since Φ_b is decreased by Φ_c and Φ_g is increased by the same amount, the change in $\beta(r, t)$ is given by

$$\begin{aligned}\Delta\beta(r, t) &= -\Phi_c[1 + \alpha(r)] \\ &= -\Phi_c\left[1 + \frac{\Phi_b(t) - \beta(r, t)}{\Phi_g(t)}\right] \\ &\simeq -\Phi_c[1 + \Phi_b(t)/\Phi_g(t)] \qquad (4)\end{aligned}$$

since $\beta(r, t) \ll \Phi_b(t)$ for all r within the region of stable orbits. Thus the decrease in $\beta(r, t)$ is very nearly the same at all radii within the stable region, and may be calculated from the ratio of betatron to guide field fluxes.

GENERAL DESIGN CONSIDERATIONS

The contraction of instantaneous circles occurs only during the time that Φ_c is changing, that is during the rise-time of the current in the contractor coil. If i_0 is the final current in the coil and τ the time constant of the inductance L and resistance R of the circuit, then the initial rate of change of current is i_0/τ and the corresponding rate of change of contractor flux is given by:

$$\dot{\Phi}_c = Li_0/n\tau \qquad (5)$$

where n is the number of turns in the coil. Putting τ equal to L/R and i_0 equal to V/R, where V is the total e.m.f. in the circuit, we have:

$$\dot{\Phi}_c = V/n \qquad (6)$$

Some of the more important parameters of the Oxford synchrotron are listed in the table. From this data, the decrease in $\beta(r, t)$ required to displace instantaneous circles clear of the gun structure was estimated to be 0·45 kilolines for an injection energy of 100 keV, and the corresponding reduction in betatron flux Φ_c is 0·20 kilolines. If this displacement is to occur in the time of, say, two revolutions (0·036 μs), then the e.m.f. per turn required is given by

$$\begin{aligned} V/n &= 5{\cdot}5 \text{ kilolines}/\mu\text{s} \\ &= 55 \text{ V/turn} \end{aligned} \tag{7}$$

The back e.m.f. induced by the change in the main betatron flux Φ_b at this part of the cycle is 117 V/turn, which is more than enough to energize the coil.

Parameters of the Oxford synchrotron

General	
Peak energy	125 MeV
Repetition frequency	50·5 c/s
n at equilibrium orbit	0·55
Equilibrium orbit radius	46·7 cm
Radial extent of stable region	43·8–49·8 cm
Gun radius (to filament axis)	49·5 cm
Projection of gun anode beyond filament axis	<0·5 cm
For 100 keV injection	
B at equilibrium orbit	24 G
$\dot{B}$ at equilibrium orbit	1·19 G/μs
$\dot{\Phi}_b$	11·7 kilolines/μs
Φ_b/Φ_g	4/3
$\beta(r, t)$ at gun radius	−6·3 kilolines
$\partial\beta(r, t)/\partial r$ at gun radius	−0·9 kilolines/cm

In addition to obtaining a sufficiently fast initial rate of contraction, it is desirable to maintain almost this rate throughout the injection period. This means that the time constant τ should be longer than the time of acceptance into stable orbits, thought to be of the order of 0·1 μs. An upper limit to the final contractor flux Φ_{co} and hence, for a fixed initial rate of contraction, to τ is set by the fact that, if the total displacement of orbits is too great, electrons will be lost by vertical instability near the inner radius of the stable field region. The best compromise between a fast initial rate of contraction, a long duration of this rate and a not too large total displacement can only be found empirically, but for design purposes an upper limit on the total displacement was taken as sufficient to contract from gun radius to equilibrium orbit radius. This corresponds, according to the data of the table, to a maximum Φ_{co} of 2·7 kilolines.

The reluctance of the magnetic circuit of betatron bars in series with the main gap (see Fig. 1) is $1{\cdot}4 \times 10^{-3}$ c.g.s. units, and therefore the maximum magnetomotive force required is 3·0 ampere-turns.

THE CONTRACTOR CIRCUIT

The basic circuit of the contractor is shown in Fig. 2(*a*). L is the contractor coil, and R a variable resistor controlling the time constant τ. The switch S is closed at injection, and the total e.m.f. around the circuit is equal to the induced e.m.f. 117 n volts minus the battery voltage v. By varying v, the final contractor flux can be controlled. The switch S was, in practice, a small thyratron, type EN31 (by Mullard Ltd.), triggered on by a positive pulse on its grid. The thyratron continues to conduct until, due to saturation of th betatron bars, the induced e.m.f. falls below v. This occu approximately 400 μs after injection, and since the machin operates at 50 c/s, the duty cycle of the valve is roughly 1/5 Waveforms of the induced e.m.f. and the contractor co current are shown diagrammatically in Fig. 3.

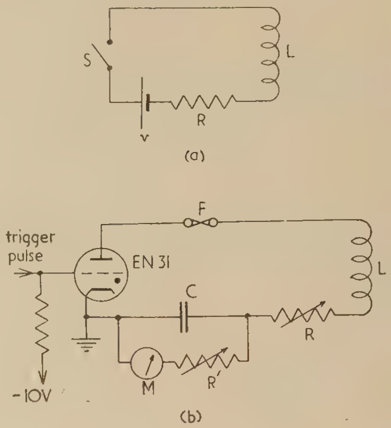

Fig. 2. (*a*) Basic circuit of contractor; (*b*) practical circuit

R, 150–1500 Ω, 1 W; R', 20–120 kΩ, 20 W; C, 10 μF paper, 600 V; M, 0–10 mA meter; F, 60 mA fuse.

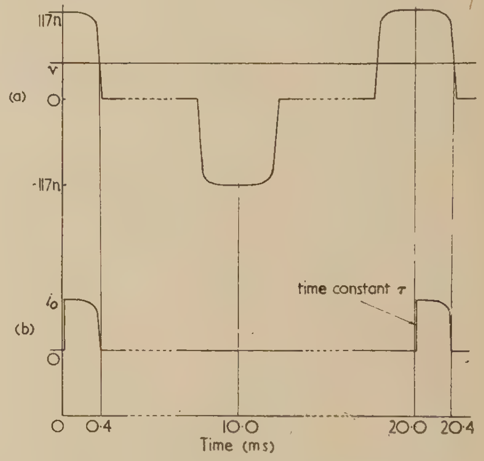

Fig. 3. Waveforms of (*a*) induced e.m.f. and (*b*) current in the contractor coil

The number of turns on the coil was chosen to suit th maximum ratings of the EN31 thyratron. The maximu mean current for this valve, 10 mA, sets a limit of 500 m on i_0 for the duty cycle of 1/50, less than the maximum pea rating of 750 mA. To give a maximum m.m.f. of 3 amper turns, a six-turn coil was used. The maximum induced e.m was then 700 V, as compared with a peak anode volta rating of 1 kV.

The voltage v was obtained from the rectified current flo ing through the thyratron, by allowing this to charge up capacitor C, as shown in the detailed circuit Fig. 2(*b*). T voltage v was controlled by a variable leakage resistor across this capacitor, the time constant being in all cas large compared with 20 ms, the period of the magnet.

The time of firing of the thyratron was controlled i dependently of the time of the injection pulse on the electr gun.

PERFORMANCE

he resistors R and R' were preset to give maximum chrotron output, and only the timing control is adjusted ing operation of the machine. The optimum values, = 650 Ω and $R' = 60$ kΩ, correspond to a time constant f 0·5 μs and a final contractor flux Φ_{co} of 2·0 kilolines. se values are not critical, a change of 20% in τ or Φ_{co} sing only a few per cent fall in output. The timing istment, however, had to be made to within 0·1 μs or

.

he contractor has now been in operation for almost two s, and has been used in conjunction with several different tron guns. The increase in output on switching on the tractor has never been less than a factor of three, and often been as large as a factor of twenty. The increase enerally smallest when the output without the contractor reatest. This seems to be a feature common to all similar tractors.(1)

he chief merits of this type of contractor are its simplicity reliability. Its application is limited to betatron-started chines with external injection, and to machines where the of change of betatron flux is sufficient to provide an quate driving e.m.f. This latter condition is satisfied for most machines (with the possible exception of very low energy synchrotrons) using injection energies below 100 keV. However, since the contractor flux required increases with injection energy, whereas the rate of change of betatron flux is approximately independent of injection energy, separate excitation of the contractor coil would probably be necessary if high energy injection (e.g. by a Van de Graaff accelerator) were used.

REFERENCES

(1) Adams, G. D. *Rev. Sci. Instrum.*, **19**, p. 607 (1948).

(2) Davis, L., Jr. *Rev. Sci. Instrum.*, **21**, p. 971 (1950).

(3) Jones, W. B., Kratz, H. R., Lawson, J. L., Ragan, G. L., and Voorhies, H. G. *Phys. Rev.*, **78**, p. 60 (1950).

(4) Wideröe, R. *J. Appl. Phys.*, **22**, p. 362 (1951).

(5) Barden, S. E. *Proc. Phys. Soc.* [*London*] *B*, **64**, p. 579 (1951).

(6) *Massachusetts Institute of Technology Laboratory of Nuclear Science, Annual Progress Report*, p. 141 (1954–5).

(7) Amaldi, E., and Ferretti, B. *Rev. Sci. Instrum.*, **17**, p. 389 (1946).

(8) Kerst, D. W. *Phys. Rev.*, **74**, p. 503 (1948).

A precision, direct-reading, colour temperature meter

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The measuring element in the instrument described is a photomultiplier tube operated in a logarithmic difference circuit which views, alternately through red and blue filters, a diffuser illuminated by the lamp which is being calibrated. The output from the circuit is linearly proportional to the reciprocal of the colour temperature of the lamp and is independent of its brightness. Readings can be made with an accuracy of approximately ±5° K over the colour temperature range from 2200 to 3200° K.

e method of determining the colour temperature of a grey ly, such as a tungsten filament, is to measure the relative ission from it at any two wavelengths. This can be done using two receivers with different spectral sensitivities,(1) by using appropriate filters with a single photocell.(2, 3)

Several colour temperature meters based on this principle ve been described. These are essentially null-reading truments in which some device is adopted to balance the tput at one wavelength against the output at the other. e method is to use diaphragms of variable areas, or neutral ers, to control the output from the two cells.(4, 5) Alterna- ely, where a single photocell is used, a blue wedge can be lized for this purpose in conjunction with a rotating er, half red and half blue.(6, 7) With these instruments, our temperature measurements are normally carried out obtaining balance, first with the test lamp by adjustment the wedge and then with a standard lamp by adjustment the voltage applied to it. This procedure is necessarily her cumbersome. Alternatively, the balancing wedge or utter can be directly calibrated in terms of colour tempera- e, but such a calibration usually does not follow any ple law.

These defects have been overcome in the instrument scribed in the present paper by utilizing a logarithmic ference circuit to measure the ratio of the energies at two velengths. This permits direct indication of the colour nperature of a source, independent of its brightness. A ther advantage is that the output from the circuit is linearly proportional to the reciprocal of the colour temperature over a wide range.

THEORY OF THE INSTRUMENT

Since Wien's law is applicable at the temperatures we are considering,(8) we have, for a grey body such as a tungsten filament,

$$(E_{\lambda 1}/E_{\lambda 2}) = (\lambda_2/\lambda_1)^5 \exp\{(c_2/T)[(1/\lambda_2) - (1/\lambda_1)]\} \qquad (1)$$

where $E_{\lambda 1}$ and $E_{\lambda 2}$ are the energies emitted at wavelengths λ_1 and λ_2 respectively; or, taking logarithms,

$$\log E_{\lambda 1} - \log E_{\lambda 2} = A + B/T \qquad (2)$$

where A and B are constants for particular values of λ_1 and λ_2.

This equation is, of course, strictly applicable only to two monochromatic wavelengths, but, in practice, it holds with sufficient accuracy even for two spectral bands of appreciable width.(9)

OPTICAL SYSTEM

The layout of the optical system of the instrument is shown diagrammatically in Fig. 1. A magnesium carbonate diffuser D, illuminated normally by the lamp which is being calibrated, is imaged by the objectives O, O', on to a ground glass diffusing screen D' placed in front of the cathode of the photomultiplier tube PM. The red and blue filters R

and *B* are located between the objectives behind an aperture *A*, 3 mm wide and 1 cm high, and are mounted side by side on a vane attached to the end of the armature of a centre stable relay *RL*. This is driven by a multivibrator circuit at a frequency of 5 c/s, so that the beam of light defined by the aperture *A* alternately passes through one or the other of the filters.

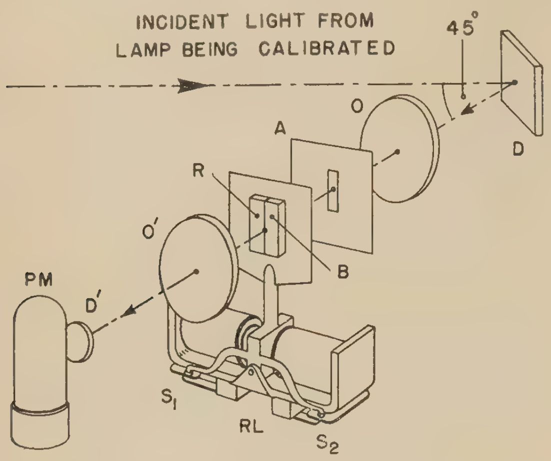


Fig. 1. Layout of the optical system

D, magnesium carbonate diffuser; *O*, *O′*, objective lenses, 15 cm focal length; *A*, aperture; *R*, red filter; *B*, blue filter; *D′*, ground glass diffuser; *PM*, photo-multiplier; *RL*, centre stable relay; S_1, S_2, relay contacts.

THE MEASURING CIRCUIT

The logarithmic difference circuit employed in this instrument is a simplified version of that used in a ratio-recording spectrophotometer attachment designed by the authors,$^{(10)}$ and employs a photomultiplier tube operated at constant anode current as the light-sensitive element. A negative feedback loop controls the voltage between successive dynodes, and, thereby, the overall gain of the tube, so that the anode current does not change as the light flux on the photocathode varies.$^{(11)}$ Under these conditions, the relation between the light flux F and the dynode voltage V is of the form

$$F \propto (V/V_1)^{-N\beta} \tag{3}$$

where V_1 and β are tube constants and N is the number of dynode stages.

If the dynode voltage is then applied to an amplifier with a logarithmic response, the output voltage v is given by the relation

$$v = -(1/N\beta) \log F + K \tag{4}$$

where K is a constant.$^{(12)}$ The output voltage is therefore proportional to the logarithm of the incident light flux.

Since the factor $N\beta$, which may be termed the range compression factor, is of the order of 6·6 for most commercial nine-stage photomultiplier tubes,$^{(13)}$ a logarithmic response can be obtained over a fairly wide range with an amplifier having a logarithmic characteristic over a comparatively restricted range. In this case, because the illumination range to be handled by the instrument was less than 300 : 1, it was found possible to use a variable μ-tube as the logarithmic amplifier.$^{(12)}$

Since the two filters alternate in the beam of light incident on the photomultiplier, the output from the logarithmic amplifier fluctuates at a frequency of 5 c/s. Each cycle consists of two sections, one corresponding to the red filter and the other to the blue filter. These two signals a separated by a synchronous switch which feeds alterna half cycles to each of the two grids of a difference amplifi By introducing storage capacitors in the grid circuits, t two sections of the difference amplifier are made essentia peak reading, so that the output current from this stage proportional to (log E_R − log E_B) where E_R and E_B represe the intensities of the red and blue beams respectively. follows then, from equation (2), that the output current fro this stage should be linearly proportional to the reciproc of the colour temperature of the source.

CIRCUIT DETAILS

The measuring circuit. Fig. 2 is a diagram of t logarithmic photomultiplier circuit. The high-voltage supp for the photomultiplier tube utilizes a half-wave rectifier and a two-section capacitor input filter. The individu dynodes are supplied from a chain of equal bleeder resisto the current through which is controlled by a negative fee back circuit consisting of a cathode follower V_7 and a ser regulator tube V_6.

An adjustable fraction of the voltage developed across t last resistor in the dynode bleeder chain is tapped off by t potentiometer RV_1 and applied to the grid of a variab μ-pentode V_8, which acts as a logarithmic amplifier. T cathode of this tube is coupled to the fixed contacts of t synchronous switch S_1, S_2. This switch utilizes the two se of contacts provided on the centre stable relay *RL*, which used for chopping the light beam, and the two movi contacts are connected to the grids of V_9 and V_{10}, which a as a difference amplifier, through resistance capacitan filters. In addition to making the circuit essentially pe reading, the filters eliminate fluctuations in the output at t chopping frequency. The output from the difference amplif is read on a 0–50 μA meter M_2 connected between the tw cathodes. The zero reading of the meter can be set with t potentiometer RV_2, and the sensitivity can be adjusted means of the variable shunt RV_3.

A separate power supply stabilized by three volta regulator tubes is used to provide the screen and catho voltages for V_6, as well as the plate voltages for V_7, V_8, and V_{10}.

The multivibrator circuit. Fig. 3 is a diagram of the circu used to drive the chopping relay. A double triode V_1, operated as a free-running multivibrator at a frequency 5 c/s, generates a square wave which is applied to the gri of two beam power tubes V_3, V_4 working as a push-pu amplifier. The two coils RL_1, RL_2 of the relay are connect in the plate circuits of V_3 and V_4. This circuit is run off separate power supply of conventional design which can gi up to 125 mA at 250 V.

FILTERS

The criteria for the selection of a pair of filters for a colo temperature comparator have been discussed at some leng by Harding$^{(4)}$ and by Brown.$^{(7)}$ For maximum sensitivity is desirable that the pair of filters used should have fai widely separated transmission bands and, at the same tim reasonably high transmission coefficients.

The blue filter utilized in the present instrument was Chance OB 10 glass, 2·2 mm thick, while the red one was Chance OR 2 glass, 2·0 mm thick. In conjunction with t type 931 A photomultiplier employed as the detector, the gave effective sensitivity peaks at 4200 and 6100 Å respective Balanced output was achieved with a source of colo

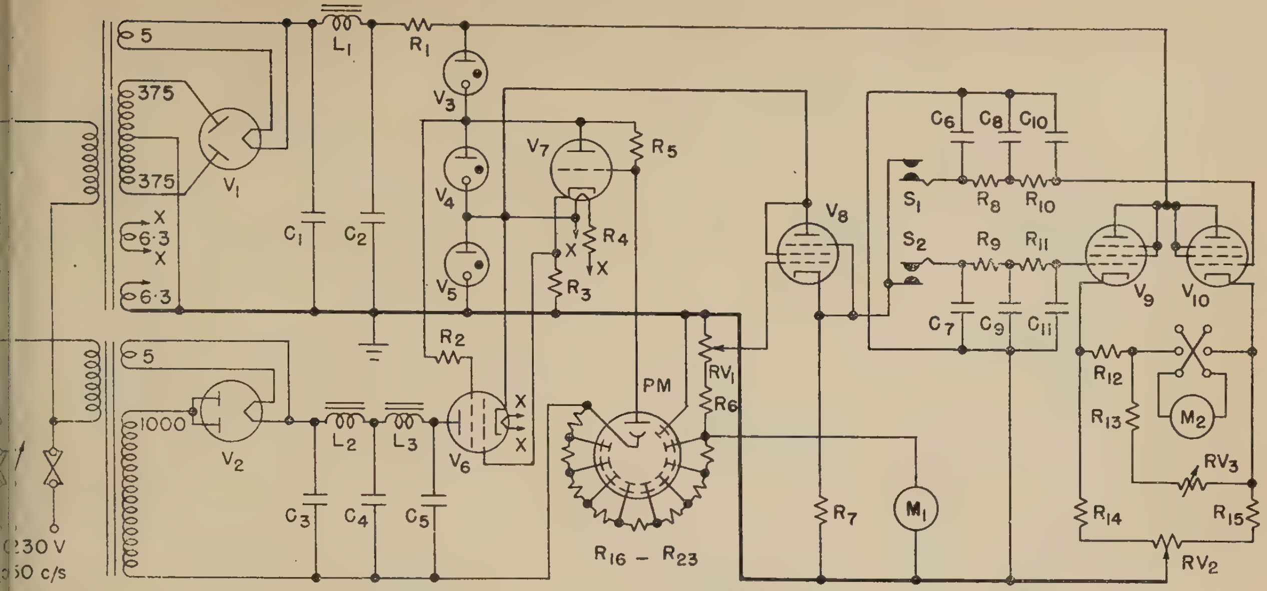

5
375
375
X
6·3
X
6·3
5
1000
30 V
0 c/s
V1
L1
R1
V3
V4
V5
C1
C2
V7
R5
R4
X
X
R3
R2
X
X
V6
L2
L3
C3
C4
C5
PM
RV1
R6
R16 – R23
R7
M1
V8
C6
C8
C10
S1
R8
R10
S2
R9
R11
C7
C9
C11
V9
V10
R12
R13
M2
RV3
R14
R15
RV2

Fig. 2. Diagram of the measuring circuit. Wire wound resistors are use throughout, with the exception of R_3, R_5 and R_8–R_{11}

$_1$ = 4 kΩ
$_2$ = 1 kΩ
$_3$ = 330 kΩ
$_4$ = 5 Ω
$_5$ = 150 MΩ
$_6$ = 5 kΩ

R_7 = 10 kΩ
R_8–R_{11} = 1 MΩ
R_{12} = 4 kΩ
R_{14}, R_{15} = 2·5 kΩ
R_{16}–R_{23} = 15 kΩ

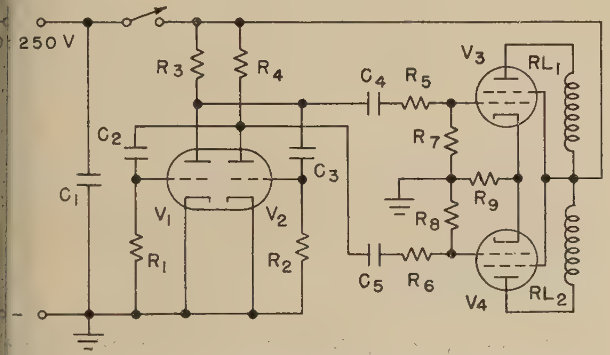
RV_1 = 10 kΩ
RV_2 = 100 Ω
L_1 = 8 H
L_2, L_3 = 20 H
S_1, S_2 = relay contacts

C_1 = 8 µF
C_2 = 32 µF
C_3–C_5 = 4 µF
C_6, C_7 = 2 µF
C_8–C_{11} = 0·1 µF

V_1 = 5Y3 GT
V_2 = 5R4 GY
V_3, V_4 = VR 75
V_5 = VR 105
V_6 = 807
V_7 = 6SF5

V_8 = 6SK7
V_9, V_{10} = 6AC7
PM = 931 A
M_1 = 0–150 V, 20 kΩ/V
M_2 = 0–50 µA

perature about 2450° K, and the colour temperature ge from 3300 to 2200° K could be covered with adequate sitivity.


250 V
R3
R4
C4
R5
V3
RL1
C2
R7
C3
C1
V1
V2
R9
R8
R1
R2
C5
R6
V4
RL2

ig. 3. Diagram of the circuit used for driving the hopping relay. All resistors are ±10%, 1 W carbon, except where otherwise specified

R_1, R_2 = 470 kΩ
R_3, R_4 = 15 kΩ
R_5, R_6 = 150 kΩ
R_7, R_8 = 1 MΩ
R_9 = 300 Ω, 10 W

C_1 = 32 µF

C_2, C_3 = 0·05 µF
C_4, C_5 = 1 µF

V_1, V_2 = 6SN7 GT
V_3, V_4 = 6V6 GT

RL_1, RL_2 = relay coils, 12 V, 100 mA

CALIBRATION AND PERFORMANCE

The final calibration of the instrument was carried out on hotometric bench using a standard lamp. Since the nsfer characteristics of the type 6SK7 variable µ-pentode are closely logarithmic for grid potentials between −12·5 1 −30 V,(12) the potentiometer RV_1 was initially set so t this range of input voltages was obtained when the ode voltage varied from 50 to 120 V per stage, which is best operating region for the photomultiplier. The tance of the lamp from the diffuser was then adjusted so that the dynode voltage was within this range, as indicated by the meter M_1. With lamps of wattages ranging from 15 to 100, this condition could be usually achieved with the lamp between 1 and 2 m from the diffuser.

A typical calibration curve obtained with the instrument is shown in Fig. 4. The scale of the output meter normally

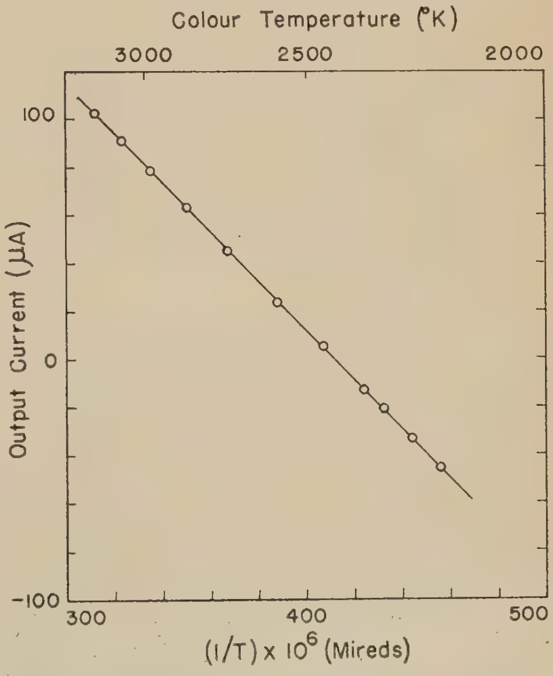


Fig. 4. Calibration curve of the instrument obtained with a standard lamp. The output current in the meter circuit is shown as a function of the reciprocal of the colour temperature of the lamp

covers the colour temperature range from about 3200 to 2450° K, but, by means of the reversing switch provided, it can be extended to lower colour temperatures. As can be seen, the readings of the output meter are closely proportional to the reciprocal of the colour temperature of the lamp over a wide range. In practice, it was found that readings could be made with an accuracy of ±5° K at a colour temperature of 3200° K and ±3° K at 2360° K, corresponding to an accuracy of ±0·5 mired(14) over this range. These readings could be repeated to the same order of accuracy on several different occasions.

Systematic errors due to changes in the lateral position of the source, as well as its distance from the diffuser, were found to be well within the above limits owing to the arrangement of diffusers adopted. In addition, the stability of the circuit was found to be very good. After a warm-up period of a few minutes, no noticeable drift could be observed in the readings.

CONCLUSIONS

The direct-reading colour temperature meter described in the present paper combines accuracy with ease of operation. Because of the speed with which readings can be taken, it is particularly useful where routine colour temperature measurements have to be carried out on a number of lamps at specified voltages.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Winch, G. T. *J. Sci. Instrum.*, **6**, p. 374 (1929).

(2) Preston, J. S. *Proc. Phys. Soc.* [*London*], **47**, p. 10 (1935).

(3) Middleton, W. E. K., and Ramsey, A. R. *Canad.* *Res.* (*A*), **26**, p. 23 (1948).

(4) Harding, H. G. W. *J. Sci. Instrum.*, **29**, p. 145 (195

(5) Sweet, M. H. *J. Opt. Soc. Amer.*, **30**, p. 568 (1940).

(6) Sharp, C. H. *J. Opt. Soc. Amer.*, **20**, p. 62 (1930).

(7) Brown, W. J. *J. Sci. Instrum.*, **31**, p. 469 (1954).

(8) Harding, H. G. W. *Proc. Phys. Soc.* [*London*] **63**, p. 685 (1950).

(9) Russell, H. W., Lucks, C. F., and Turnbull, L. *J. Opt. Soc. Amer.*, **30**, p. 248 (1940).

(10) Hariharan, P., and Bhalla, M. S. *J. Opt. Soc. Ame* **47**, p. 378 (1957).

(11) Sweet, M. H. *Electronics*, **19**, (11), p. 105 (1946).

(12) Hariharan, P., and Bhalla, M. S. *Rev. Sci. Instru* **27**, p. 3 (1956).

(13) Rodda, S. *Photo-electric Multipliers*, pp. 48, (London: Macdonald and Co. Ltd., 1953).

(14) Priest, I. G. *J. Opt. Soc. Amer.*, **23**, p. 41 (1933).

A temperature-chlorinity-depth recorder for use at sea

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An instrument for recording temperature, chlorinity and depth in the upper 1000 metres of the sea is described. The temperature range is 0–30° C, with an accuracy of ±0·15° C. The chlorinity range spans about seven parts per thousand of chlorinity, the accuracy being ±0·03 parts per thousand. The accuracy in depth is ±10 m. The three quantities are recorded sequentially by a single-pen strip-chart recorder, each quantity being recorded for five seconds at a time. The underwater unit is suspended by means of an armoured steel cable, which has a single electrically-insulated core. This core carries power down to the underwater unit, and brings up the signals from the measuring elements. A simple frequency-modulation method of telemetering is used.

The standard method for the measurement of temperature and chlorinity in the sea is by the use of special reversing thermometers, and the collection of samples, the chlorinity of which is obtained by titration against silver nitrate. [Chlorinity (Cl) is defined by the equation $Cl = (S - 0{\cdot}03)/1{\cdot}805$, where S is the salinity, or concentration of salt in parts per thousand (p.p.t.) by weight. The average chlorinity of sea water is about 19·5 p.p.t.]. This method, although capable of high accuracy, has the following disadvantages: (i) the measurements are made at pre-set depths, so that important detail may be missed; (ii) the chlorinity information is not usually available quickly enough to be useful in guiding the progress of a cruise; and (iii) sampling and analysis are time-consuming and therefore expensive. These disadvantages can be largely overcome by a continuously-recording instrument. Such an instrument (the bathythermograph(1)) is in wide use for temperature measurements, but present models cannot be used to a depth greater than 300 m.

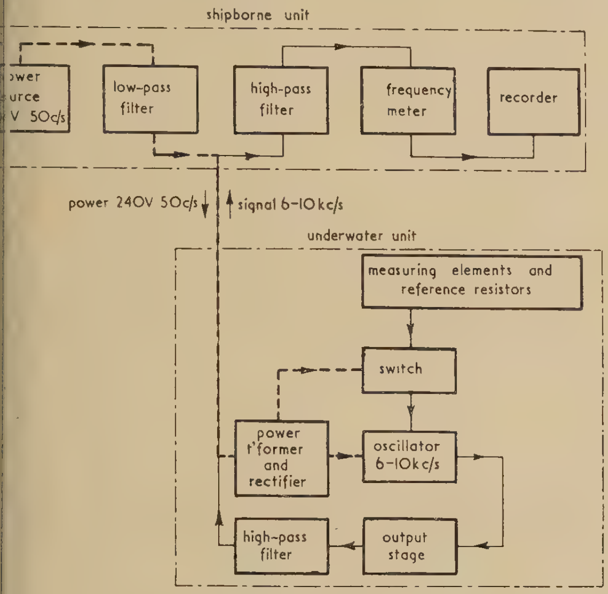
A recording instrument for both chlorinity and temperatu was described in 1948 by Jacobsen.(2) This instrument w designed for a maximum depth of 400 m, and had accuracy of only 0·15 p.p.t. in chlorinity. Separate su porting and electrical cables were used.

The present instrument was designed for a maximum dep of 1000 m, since the main ocean currents, and therefore t most important variations in water properties, occur abo this depth. Accuracies of the order of ±0·1° C in te perature and ±0·03 p.p.t. in chlorinity were aimed at. Th accuracies are inferior to those obtained by reversing therm meters and titration of chlorinity samples, but are conside sufficient for many purposes, such as the recognition of wa masses of different origin, and the calculation of relat currents above 1000 m in temperate latitudes from the dens field.

A feature of the design of the present instrument is t use of a single-cored armoured steel cable as the o iexion between the underwater unit and the ship. This e carries power from the ship down to the underwater brings up the measuring signals, and also supports the weight of the underwater unit. This feature greatly lifies handling the equipment at sea.

GENERAL DESCRIPTION

ie instrument consists of a shipborne unit and an underr unit, connected by a single-cored armoured cable. A k diagram is shown in Fig. 1. The measuring elements



ig. 1. Block diagram of the temperature-chlorinity-depth recorder

ie underwater unit are essentially variable resistors with es depending on chlorinity, temperature or depth. These ients are connected in turn, by means of a switch, to an llator, the frequency of which is a function of resistance. his way the measured variables are converted into frencies in the range 6000–10000 c/s. The output of the llator is fed to the central core of the cable, the outer l sheath acting as return conductor.

n board ship, the up-coming signals are separated from power circuit by a high-pass filter, and are fed to a frency meter. This unit gives a d.c. output proportional to input frequency. The d.c. output is recorded on a edomax type G recorder (by Leeds and Northrup Co., .A.), a suitable backing-off voltage being applied so that full scale of the recorder can be used.

o provide an overall check on the instrument, and eliate the effects of drift in the oscillator and frequency er, fixed reference resistors are connected to the oscillator egular intervals. These resistors give oscillator frequencies esponding to readings of 1 and 14 on the recorder chart le 0–15). Adjustments are provided in the frequency er so that the pen can be positioned exactly on the ropriate chart reading when the reference resistors are circuit. This feature eliminates almost all sources of r and drift except, of course, the measuring elements nselves.

he switch in the underwater unit is an eleven-position ping relay. It is arranged to operate every five seconds, and connects the measuring elements and reference resistors in the following order:

Switch position	*Quantity measured*
1	Temperature
2	Chlorinity
3	Depth
4	Upper reference
5	Temperature
6	Chlorinity
7	Depth
8	Lower reference
9	Temperature
10	Chlorinity
11	Depth

The underwater unit is lowered and raised at a maximum rate of 100 m/min with the vessel hove to. At this rate successive measurements of a given quantity may be separated by as much as 33 m in depth. More detail can be obtained by raising more slowly through depth regions of particular interest.

The recorder has a full-scale range of 20 mV, so that it is suitable for measuring surface currents by the method of towed electrodes.(3) The necessary switching and controls for this application have been built into the shipborne unit, but will not be further described in this paper.

OSCILLATOR

A simplified circuit of the oscillator(4) is shown in Fig. 2. The oscillator is of the resistance-capacitance or phase-shift type which are generally well known, but this particular circuit has one feature that makes it most suitable for the present application—the frequency depends on the ratio of two resistors (R_6 and R_7), and is independent of the magnitude of either, within reasonable limits. The use of this property in the measurement of chlorinity is dealt with in a later section.

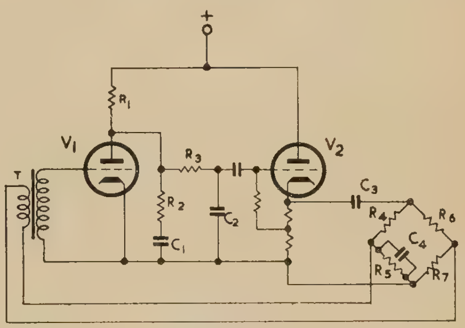


Fig. 2. Simplified oscillator circuit

If the bridge network on the right-hand side of Fig. 2 is nearly in resistive balance, there will be a phase shift of about 90° between the bridge output and input voltages, due to capacitor C_4. This phase shift does not alter rapidly with either frequency or the value of C_4, but is very sensitive to the state of resistive balance of the bridge.

The circuit oscillates at a frequency for which the sum of the phase shifts in the bridge and in the network R_1, R_2, R_3, C_1, C_2 is zero. The phase shift in the latter network is frequency-dependent, so that the frequency of oscillation depends critically on the ratio R_6/R_7. The value of C_4 determines the sensitivity, that is the fractional change in frequency, for a given fractional change in R_6 or R_7. Small values of C_4 give high sensitivity, but require a correspondingly high gain in the amplifying stage (V_1).

Resistor R_2 is not essential to the basic oscillator, but was added and adjusted empirically to obtain a linear relationship, over a specified range, between frequency and the resistance of R_7. As will be shown later, this enables a standard linearly-divided recorder chart to be used, with direct-reading scales for both temperature and depth. The adjustment of R_2 to give linearity is not critical, since the relationship is only slightly curved when R_2 is zero. After adjustment of R_2, the frequency is related to R_6 and R_7 by an expression of the form

$$f = A - BR_7/R_6 \qquad (1)$$

where A and B are constants.

To avoid unwanted phase shifts, which make the frequency slightly dependent on the magnitude of R_6 and R_7, the reactance of C_3 must be very small, and the input impedance of transformer T very large, compared with the resistances of the bridge.

MEASURING ELEMENTS

In the actual instrument, the simple bridge on the right of Fig. 2 is replaced by the circuit of Fig. 3. The stepping switch makes connexion to C_3 and the input winding of transformer T (Fig. 2) according to the following table.

Quantity	*Transformer leads connected to*	*C_3 connected to*
Chlorinity	1, 2	8
Temperature	3, 4	9
Depth	3, 5	9
Upper reference	3, 7	9
Lower reference	3, 6	9

It will be seen from Figs. 2 and 3 and the table that the measuring elements and reference resistors are connected in turn in the position occupied by R_6 and R_7 of Fig. 2; R_4, R_5 and C_4 are duplicated in Fig. 3 only for ease of adjustment.

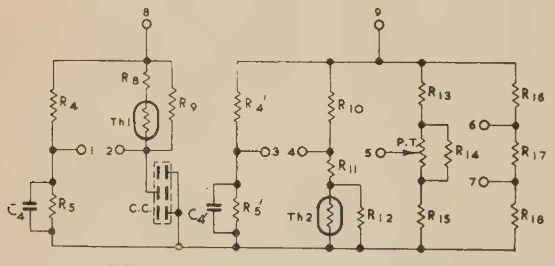


Fig. 3. Oscillator bridge circuit

C.C., conductivity cell; Th_1, thermistor (Standard Telephones and Cables, type F2311) to compensate the effect of temperature on conductivity; Th_2, thermistor (type F2200) for temperature measurement; P.T., pressure transducer; R_{16}–R_{18}, reference resistors.

Although one thermistor could have been used for both temperature measurement and compensation of the conductivity cell (see below) it is more convenient to use separate thermistors as shown in Fig. 3. This has the advantage that none of the contacts of the stepping switch is in series with a bridge arm, so that the effects of contact resistance changes are minimized.

CHLORINITY

Chlorinity is measured by means of a conductivity c with platinized platinum electrodes. The effect of te perature on conductivity is compensated by using thermistor.(5, 6) The thermistor Th_1 (Fig. 3) has fix resistors R_8 and R_9 in series and in parallel, with valu chosen so that the temperature coefficient of the bridge a containing the thermistor is, as nearly as possible, equal that of the conductivity cell for sea water of average chlorinit Over the temperature range 5–24° C, in which nearly readings taken with the instrument will fall, compensati to within ±0·01 p.p.t. chlorinity can be attained. Sma corrections can be applied for temperatures outside th range. Fig. 4 shows a typical graph of corrections as function of temperature, obtained by laboratory calibrati with water of chlorinity 19·55 p.p.t. As pointed out Dorrestein(5) the temperature coefficient of conductivit nearly independent of chlorinity, so that the correctio shown in Fig. 4 can be applied for any chlorinity, at le within the range normally encountered in the open se Formulae for calculating R_8 and R_9 have already be published.(6)

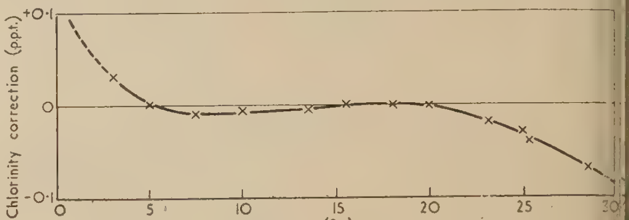


Fig. 4. Chlorinity correction as a function of temperature, for water of chlorinity 19·55 p.p.t.

Since the ratio of the bridge arm containing thermist Th_1 to the resistance of the conductivity cell is almost ind pendent of temperature, the frequency of the oscillator, an hence the recorder deflexion, will be a function of chlorin only, if the effect of pressure is neglected for the present.

The chlorinity scale on the recorder is neither linear n direct reading, the relationship between chart deflexion an chlorinity being very nearly of the form

$$S = C - D/Cl \qquad ($$

where S is the chart reading, Cl is the chlorinity and C and are constants. However, the range of chlorinity in the op sea is so small that the above relation may be replaced by linear one, and the various constants have been chosen that one chart division (3·4 mm) corresponds to a change approximately 0·1 p.p.t. at a chlorinity of 19·5 p.p.t. Th gives a rather cramped chlorinity scale, but has the advanta that conductivity cells with slightly different constants ma be interchanged without adjusting any of the fixed resisto of the bridge network.

It was found necessary to avoid direct electrical connexi between either conductivity cell lead and the pressure vess as such a connexion allowed electrolytic currents to flow an caused rapid polarization of the electrodes. The oscillat circuit and its power supply are therefore isolated from th pressure vessel for d.c., but effectively earthed for a.c. by 4 μF capacitor.

After initial trials with glass conductivity cells mounte on metal stems, a more reliable and robust cell was mad from an epoxy casting resin (Araldite type D). Fig. 5 sho ross-section of the cell. It is electrically similar to the used in the portable temperature–chlorinity bridge.(6) mounting flange was machined after casting and is bolted he side of the pressure vessel, using an O-ring seal in a ove machined in the pressure vessel.

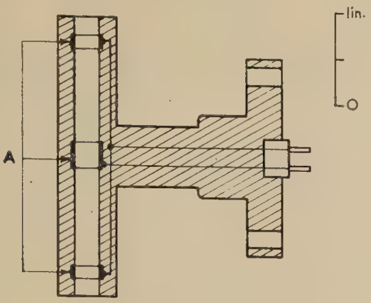


Fig. 5. Conductivity cell. *A*, platinum foil electrodes

he change of conductivity with pressure must be allowed in interpreting the chlorinity records. Measurements of effect have been made and will be reported elsewhere.(7) pressure effect depends slightly on temperature, but a ection of −0·026 p.p.t. of chlorinity per 100 m depth been found satisfactory, and the dependence on tempera- can be neglected for most work.

TEMPERATURE

emperature is measured by means of a thermistor (type 200 by Standard Telephones and Cables Ltd.). Ther- ors of this type have been tested to 3000 lb/in.^{2} without ire, and such pressures have no effect on their resistance constant temperature. The thermal time constant in ed water was found to be 0·2 s, which is low enough for application.

odification of thermistor characteristics to obtain a ar law has been discussed by Keonijian and Schaffner,(8) Beakley.(9) In the present case, an overall calibration ar to ±0·1° C from 5 to 30° C can be obtained by a le resistor (R_{12}, Fig. 3) in parallel with the thermistor. s resistor is chosen so that

$$R = R_0(1 - Kt) \qquad (3)$$

re R is the resistance of the thermistor and fixed resistor arallel, t is the temperature (° C) and R_0 and K are con- its. Resistors R_{10} and R_{11} of Fig. 3 are then chosen so the temperature scale of the recorder is correct at zero C) and full scale (30° C). The two thermistors are inted as a single unit which is bolted to the side of the ssure vessel with an O-ring seal, similar to that used for conductivity cell. The bases of the thermistors are bedded in casting resin in a recess in a brass flange, the ls being taken through the bottom of the recess by means mall porcelain feed-through insulators.

DEPTH

epth is measured by a pressure transducer (type 548 by angham Thompson Ltd.). The transducer consists of a rdon tube actuating the moving contact of a small wire- und potentiometer (*PT.*, Fig. 3). The pressure transducer crewed into the case of the underwater unit from the de. The inside of the Bourdon tube is filled with light oil to prevent corrosion. A synthetic rubber diaphragm transmits the water pressure to the oil.

The pressure transducer output is linear, and the adjustment of the oscillator referred to above results in linearity between the chart reading and depth. To get a convenient depth scale, full-scale deflexion on the recorder is made to correspond to 1500 m, although the transducer is designed for only 1000 m.

The effect of temperature on the accuracy of depth measurements was checked in the laboratory. No significant effect was found in the temperature range 9 to 20° C.

UNDERWATER UNIT AND CABLE

The pressure vessel was made from the two ends of an oxygen cylinder, and is 26 in. long and 8 in. outside diameter. A flange was brazed to each piece, and machined and threaded for an O-ring seal and threaded clamping ring. The vessel was hot-dip galvanized before machining.

The electrical components are mounted on an X-shaped chassis which is supported inside the vessel by blocks of sponge rubber at each end. The conductivity cell and thermistors, which protrude from the side of the vessel, are protected from damage by $\frac{3}{16}$ in. thick steel guards that clamp around the vessel.

The cable is clamped in a block which is connected to a frame on top of the vessel by a few links of chain. This prevents damage due to bending of the cable just outside the clamp. The cable continues with some slack below the block, and terminates in a specially-designed plug which mates with a socket set in the top of the vessel. This enables the pressure vessel to be separated from the cable for storage and transport without disturbing the seal on the end of the cable.

The overall length of the underwater unit, including chain and cable clamp, is 36 in., and the weight 130 lb in air and 100 lb in water. The cable, type 1–HO, is manufactured by the American Steel and Wire Co. It has a single insulated core, and two layers of galvanized steel armouring. The outside diameter is 0·183 in., and the breaking strain 2700 lb.

Electrical circuit of underwater unit. Fig. 6 is a complete circuit of the underwater unit, except that the details of the oscillator bridge circuit (Fig. 3) have been omitted for clarity.

The level of oscillation is stabilized by voltage fed to the grid of V_1 from the automatic gain control rectifier V_4. This ensures almost linear operation in the oscillator, and improves the frequency stability. The level of oscillation must be adjusted so that the voltage applied to the bridge does not exceed 1 V r.m.s., to minimize self-heating of the thermistors. The filter following the automatic gain control rectifier determines the rate with which the oscillator reaches its new equilibrium after each operation of the switch, and was chosen to make this as rapid as possible.

The oscillator is remarkably stable with respect to mains voltage changes. For voltage changes from −25 to +12% of nominal, the frequency was found to remain within ±0·05%. The error that would be produced in temperature measurement by this small frequency change is less than ±0·05° C.

The eleven-position stepping relay *Rel.* 2 is operated by an impulse obtained by discharging an electrolytic capacitor C_{18}. Discharge of C_{18} is controlled by a relay oscillator consisting of a telephone relay *Rel.* 1 and valve V_5. The time between successive impulses can be altered by adjusting either C_{17} or R_{19}. Although none of the stepping relay contacts is in series with a bridge arm, it has been found that

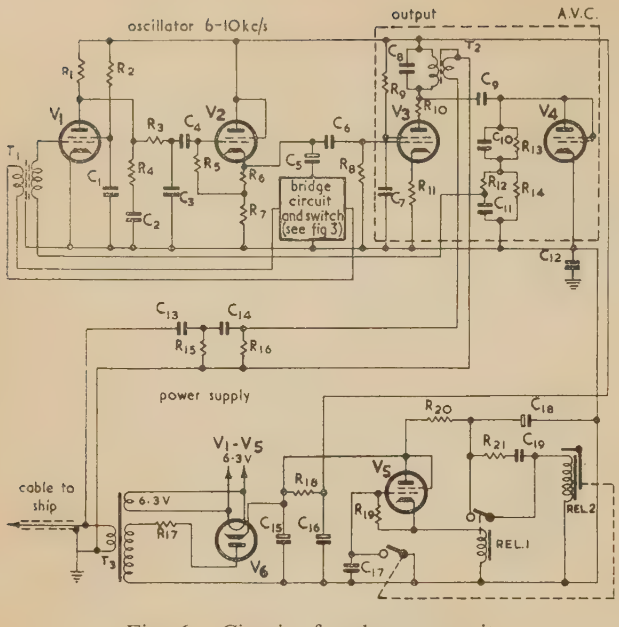

oscillator 6-10kc/s
output
A.V.C.
R_1
R_2
V_1
R_3
C_4
V_2
C_6
T_1
C_1
R_4
R_5
C_3
C_2
C_5
R_6
R_7
R_8
bridge circuit and switch (see fig 3)
C_8
T_2
R_9
V_3
R_{10}
C_9
V_4
C_{10}
R_{13}
R_{11}
C_7
R_{12}
R_{14}
C_{11}
C_{12}
C_{13}
C_{14}
R_{15}
R_{16}
power supply
V_1-V_5 6·3V
R_{20}
C_{18}
R_{21}
C_{19}
V_5
R_{18}
cable to ship
6·3V
R_{19}
REL.2
R_{17}
C_{15}
C_{16}
REL.1
T_3
V_6
C_{17}

Fig. 6. Circuit of underwater unit

R_1 = 68 kΩ
R_2, R_3 = 220 kΩ
R_4 = 15 kΩ
R_5 = 1·5 MΩ
R_6 = 220 Ω
R_7 = 6·8 kΩ
R_8 = 470 kΩ
R_9 = 33 kΩ
R_{10} = 2·2 kΩ
R_{11} = 470 Ω
R_{12} = 680 kΩ
R_{13} = 110 kΩ
R_{14} = 47 kΩ
R_{15}, R_{16} = 100 Ω
R_{17} = 250 Ω
R_{18} = 2 kΩ
R_{19} = 2·2 MΩ
R_{20} = 22 kΩ
R_{21} = 100 Ω

C_1 = 0·01 μF
C_2 = 300 pF

C_3 = 200 pF
C_4 = 0·01 μF
C_5 = 40 μF
C_6 = 0·001 μF
C_7 = 0·1 μF
C_8 = 200 pF
C_9, C_{10} = 0·01 μF
C_{11} = 1 μF
C_{12} = 4 μF
C_{13}, C_{14} = 0·5 μF
C_{15}, C_{16} = 40 μF
C_{17} = 0·5 μF
C_{18} = 80 μF
C_{19} = 0·1 μF

V_1–V_5 = EF72
V_6 = EY70

Rel. 1 – telephone relay, Class A, 10 kΩ coil
Rel. 2 – stepping relay, Type 44, 120 Ω coil

a relay with standard contacts is only satisfactory for a limite period after careful cleaning of the contacts. This is pr sumably due to the low voltages and currents handled the switch. A switch with gold-plated contacts (by Aut matic Electric Telephones, U.S.A.) has been found mor satisfactory.

SHIPBORNE UNIT

The shipborne unit consists of two parts, the strip-cha recorder and the frequency meter. Both are bolted to a bul head, one above the other, and together occupy a spac 30 in. high, 20 in. wide and 12 in. deep. The frequenc meter unit carries the main switch and pilot light and a mete to check the incoming mains voltage, and the voltage supp to the underwater unit. The circuit of the frequency meter shown in Fig. 7; L_1, which resonates with the cable capac tance, and R_1 prevent the signal being short-circuited by t power supply. The incoming signal, which has an amplitu of about 0·1 V r.m.s., is separated from the power sup by a resistance-capacitance high-pass filter. It is the amplified and converted to an almost square wave by to V_3. This square wave is differentiated by capacitor and the positive and negative pulses so produced are rectifie by the diode V_4. The voltage supply for the balancing slid wire in the strip-chart recorder is obtained from the ampli high tension supply, so that the effects of changes in voltage balance out.

WINCH

The equipment is installed on the F.R.V. "Derwe Hunter," a 70 ft schooner with diesel auxiliary, operated the Division of Fisheries and Oceanography, C.S.I.R The vessel is fitted with a 10 h.p. hydraulic winch, which normally used for hydrology and collecting plankton. same winch is used for the electric cable of the temperatur chlorinity-depth recorder. The main shaft of the winc protrudes on both sides of the hydraulic motor, and cab reels can be slipped on to either end of the shaft. When

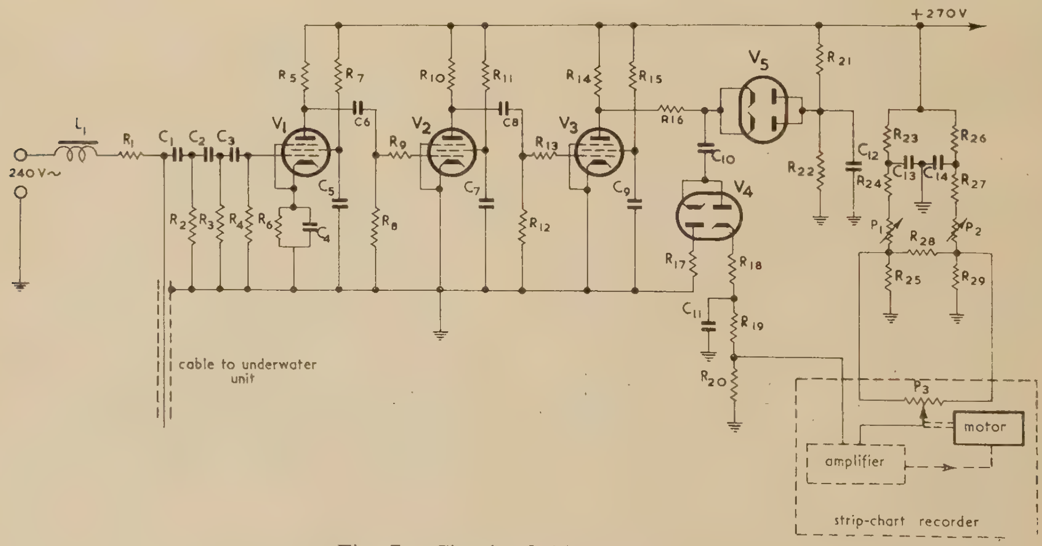

+270V
R_5
R_7
R_{10}
R_{11}
R_{14}
R_{15}
V_5
R_{21}
L_1
R_1
C_1
C_2
C_3
V_1
C_6
V_2
C_8
V_3
R_{16}
240 V∼
R_9
R_{13}
C_{10}
R_{23}
R_{26}
C_5
C_7
C_9
V_4
R_{22}
C_{12}
R_{24}
C_{13}
C_{14}
R_{27}
R_2
R_3
R_4
R_6
C_4
R_8
R_{12}
P_1
R_{28}
P_2
R_{17}
R_{18}
R_{25}
R_{29}
C_{11}
R_{19}
cable to underwater unit
R_{20}
P_3
motor
amplifier
strip-chart recorder

Fig. 7. Circuit of shipborne unit

R_1 = 100 Ω
R_2, R_3, R_4 = 0·1 MΩ
R_5 = 47 kΩ
R_6 = 300 Ω
R_7 = 222 kΩ
R_8 = 330 kΩ
R_9 = 100 kΩ
R_{10} = 10 kΩ
R_{11} = 20 kΩ

R_{12} = 330 kΩ
R_{13} = 100 kΩ
R_{14} = 27 kΩ
R_{15} = 12 kΩ
R_{16} = 27 kΩ
R_{17}, R_{18}, R_{19} = 20 kΩ
R_{20} = 152 Ω
R_{21} = 40 kΩ
R_{22} = 10 kΩ

R_{23}, R_{24} = 50 kΩ
R_{25} = 11·6 Ω
R_{26}, R_{27} = 50 kΩ
R_{28} = 1 kΩ
R_{29} = 7·02 Ω

C_1, C_2, C_3 = 500 pF
C_4 = 0·5 μF
C_5 = 0·1 μF

C_6 = 0·02 μF
C_7 = 0·1 μF
C_8 = 0·02 μF
C_9 = 0·1 μF
C_{10} = 100 pF
C_{11} = 0·5 μF
C_{12} = 0·1 μF
C_{13}, C_{14} = 4 μF

V_1, V_2, V_3 = 6 BX6
V_4, V_5 = 6AL5

L_1 = 14H

P_1 = 5 kΩ (upper reference adjustment)
P_2 = 5 kΩ (lower reference adjustment)
P_3 = balancing slidewire in strip-chart recorder

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perature-chlorinity-depth equipment is on board, the m carrying the electric cable is permanently mounted on end of the shaft, and a reel of hydrology cable on the er end. To avoid disconnecting the electric cable from underwater unit whenever the hydrology cable is being d, provision has been made for sliding the drum carrying electric cable along the shaft until it no longer meshes h the driving dogs, and clamping it in this position.

he slip rings are mounted in a weatherproof housing on outer end of the drum. The housing is prevented from ating by means of a bracket of flat steel secured to the k; the bracket is sufficiently flexible to accommodate the al movement of the drum between the driving and the mped positions.

OPERATION

The instrument is switched on for about fifteen minutes ore the station is reached, as the frequency meter drifts htly when warming up. The conductivity cell is filled a few seconds with dilute hydrochloric acid. As soon as vessel has lost way, the underwater unit is swung out- ard and lowered just below the surface. The upper and er reference marks are checked and adjusted if necessary. underwater unit is then lowered to a depth of 1000 m immediately raised again. The reference marks are erved during the record, and adjusted if necessary, a cil mark being made on the record whenever the reference trols are altered. The cable is laid as evenly as possible the drum by means of a hand-held guide. When under between stations, the underwater unit is lashed on deck inst the rail.

EXPERIENCE AND TEST RESULTS

The recorder has been operated at sea on about sixty asions in the period April 1955 to November 1957. On st of these occasions, Nansen bottles fitted with reversing rmometers were used just before or just after the recorder obtain temperatures and chlorinities for comparison with recorder. The depth readings of the recorder were cked either by attaching protected and unprotected ersing thermometers to the electric cable just above the derwater unit, or by measuring the amount of cable paid t and its inclination to the vertical.

number of weaknesses in design appeared during the ts. Most of these were of a mechanical nature (seals, plug d socket connexions, slip rings) and are probably inevitable the early stages of the development of such an instrument. is felt that these initial faults have now been rectified, hough a few minor changes will no doubt be made in future. general, the equipment has proved simple to use at sea, en from a relatively small vessel, and it has been found t the equipment can be used in the same weather con- ions as the Nansen bottles. The steel cable deteriorates idly if not treated with oil, and shows slight evidence of ting twelve months after initial use even when oiled.

The sea trials have not provided a completely satisfactory eck of the accuracy under operational conditions. The in difficulty in comparing the temperature and chlorinity ults obtained by the two different methods has been in arating the errors due directly to the temperature and orinity circuits from those produced indirectly by errors depth. Only two unprotected reversing thermometers re used on each Nansen bottle cast, and the inclination the wire to the vertical was not usually recorded, so that true depths at which the Nansen bottles were tripped were not sufficiently well known. The pressure transducer used in the recorder is not reliable to better than ±10 m, and therefore introduces further uncertainties in the comparison of temperatures and chlorinities by the two methods, especially in the thermocline region.

Taking both laboratory calibrations and sea trials into account, the following maximum errors in the three measured quantities taken separately have been estimated.

Temperature. This quantity can be read to the nearest 0·05° C, and provided corrections based on laboratory calibration are applied, appears to be accurate to ±0·15° C. The corrections depend on the accuracy with which a linear temperature scale can be achieved, and at present do not exceed 0·25° C.

Chlorinity. A maximum error of ±0·03 p.p.t. can be achieved, provided a surface sample is taken at each station and analysed independently as a check on conductivity cell drift. (Independent checks of this nature can easily be made on board, for example, by using the temperature-chlorinity bridge previously described.⁽⁶⁾) Correction for the effect of pressure on conductivity must of course be applied, and a further correction, generally not exceeding 0·02 p.p.t., should be applied for lack of exact compensation for the effects of temperature on conductivity. This correction is a function of temperature only. It is still too early to generalize on the subject of conductivity cell drift, but the following results obtained on "Derwent Hunter" Cruise 3 (April 1957) are of interest. The surface chlorinities measured with the recorder at thirteen stations in a period of eight days were consistent to ±0·02 p.p.t., but differed from the laboratory calibration made before and after the cruise by 0·04 p.p.t. There was no evidence of a consistent drift in calibration during the cruise.

Depth. The accuracy in depth appears to be about ±10 m, but to achieve this separate corrections should be used for raising and lowering, since the transducer hysteresis is of the order of 20 m. An appreciable change in depth calibration has been noticed since the initial adjustment.

Fig. 8 is a reproduction of part of a record obtained with the instrument. The figure shows the main thermocline at a

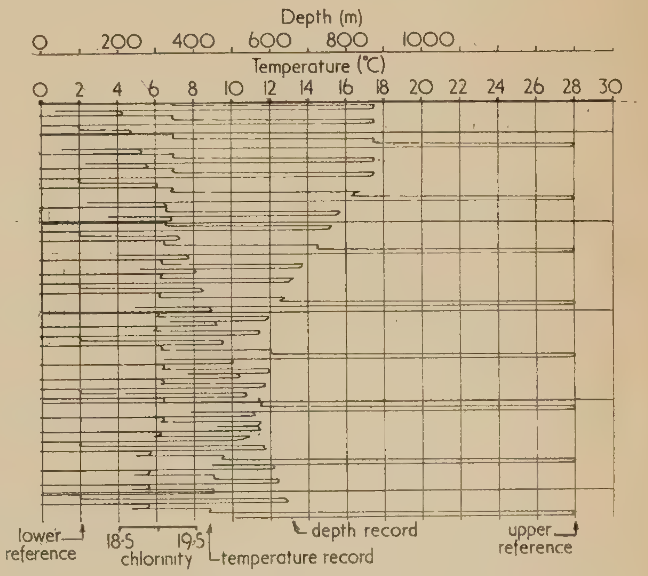

Fig. 8. Part of a record obtained while raising the instrument. The horizontal chart rulings correspond to a time interval of 2 min.

depth of 290 m, and a layer of relatively warm, saline water between 490 and 580 m.

ACKNOWLEDGEMENTS

This instrument was developed in the Division of Electrotechnology, C.S.I.R.O., following a suggestion by Mr. D. J. Rochford of the Division of Fisheries and Oceanography. The authors wish to acknowledge the help given by their colleagues in both Divisions.

REFERENCES

(1) Spilhaus, A. F. *J. Mar. Res.*, **1**, p. 95 (1938).
(2) Jacobsen, A. W. *Trans Amer. Inst. Elect. Engrs*, **67**, p. 714 (1948).
(3) von Arx, W. S. *Pap. Phys. Oceanogr. and Meteor.*, **11**, (3) (1950).
(4) Stastny, G. F., and Butts, R. F. *Tele-tech*, **12**, p. 7 (1953).
(5) Dorrestein, R. R. *Kon. Nederlands Meteor. Inst.*, *Medd en Verhand.*, **59**, p. 387 (1954).
(6) Hamon, B. V. *J. Sci. Instrum.*, **33**, p. 329 (1956).
(7) Hamon, B. V. *J. Mar. Res.* (in press).
(8) Keonjian, E., and Schaffner, J. S. *Elect. Engng*, **73**, p. 933 (1954).
(9) Beakley, W. R. *J. Sci. Instrum.*, **28**, p. 176 (1951).

A technique for the measurement of diffusion coefficients in molten salts

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A diffusion method is described in which two columns of molten salt to be interdiffused, initially separated by a gas bubble at reduced pressure, are joined by breaking a capillary and allowing external pressure to eliminate the bubble. After a period of diffusion, the salt distribution is preserved by causing the glass diffusion tube to break at the point of initial junction while the tube is still in position in the high temperature zone of the furnace. The method has been tested with a 1 : 1 $CdCl_2$–KCl mixture. The self-diffusion coefficient of cadmium is found to be 1·40 cm.^{2}sec^{-1} at 470° C, with a probable error of 2·5%. The method is applicable up to temperatures of the order of 1000° C.

The only methods developed to date by means of which diffusion coefficients in fused salt systems may be measured are the capillary method$^{(1, 2, 3)}$ and the polarographic method.$^{(4)}$ A diffusion couple method has also been used for measurements in molten oxides.$^{(5)}$ The capillary method, while having the advantage of simplicity, carries with it inherent difficulties connected with the need for rotation of the crucible and the associated end correction factor. The polarographic method suffers from similarly inherent inaccuracies, owing to the sensitivity of the limiting current to convention conditions, and to the lack of an adequate theory connecting this quantity to the diffusion coefficient. In order to investigate the existence of complex ions in molten salts, there is required a method capable of adaptation for examination of the effect of applied potential gradients upon the diffusion coefficients, a condition not easily satisfied by the capillary or polarographic methods. The diffusion couple method,$^{(5)}$ as hitherto described, gives very uncertain boundary conditions at the commencement of diffusion and only poor accuracy has been claimed for the method.

A diffusion couple type of method, applicable up to temperatures of the order of 1000° C, has been developed, in which definite conditions at the commencement and conclusion of diffusion may be accurately realized.

THEORY

The diffusion couple method involves diffusion between two columns of liquid. For an infinite cylinder of unit cross-section, with an initial concentration given by

$$c = c_0 \text{ for } x < 0, \quad c = 0 \text{ for } x > 0 \text{ at } t = 0,$$

the concentration distribution after time t is usually represented by

$$c_{(x,t)} = \frac{c_0}{2}\left[1 - \frac{2}{\sqrt{\pi}}\int_0^{x/2\sqrt{Dt}} \exp(-y^2)dy\right]$$

Equation (1) may otherwise be stated as

$$c_{(x,t)} = \frac{c_0}{\sqrt{\pi}}\int_{x/2\sqrt{Dt}}^{\infty} \exp(+y^2)dy \qquad (2$$

The total quantity of diffusing species which has crossed the boundary, $(x = 0)$, after time t, is obtained by integration of equation (2) from $x = 0$ to $x = \infty$, i.e.

$$\int_0^{\infty} c_{(x)}dx = Q - \frac{c_0}{\sqrt{\pi}}\int_0^{\infty}\left[\int_{\alpha x}^{\infty} \exp(-y^2)dy\right]dx \qquad (3$$

where $\alpha = \frac{1}{2}\sqrt{Dt}$.

Reversing the order of integration,

$$Q = c_0/\sqrt{\pi}\int_0^{\infty}\left[\int_0^{y/\alpha} \exp(-y^2)dx\right]dy \qquad (4$$

$$= c_0/2\alpha\sqrt{\pi}\int_0^{\infty} \exp(-y^2)d(y^2)$$

$$= c_0/2\alpha\sqrt{\pi}$$

Substituting for α

$$Q = c_0\sqrt{(Dt/\pi)}$$

For cross-sectional areas other than unity:

$$Q = c_0A\sqrt{(Dt/\pi)}$$

whence $\quad D = Q^2\pi/c_0^2A^2t$

The diffusion coefficient may therefore be obtained by ermination of the total quantity of diffusing species ssing a boundary in a given time, when the diffusing umns are sufficiently long to satisfy the conditions of usion into an infinite medium, i.e., no concentration nges take place at the extremities.

For evaluation of self-diffusion coefficients by the use of iotracers, this determination involves the measurement of total radioactivity contained, at the end of the diffusion, the initially non-radioactive column. Using standard iochemical methods, this activity A_1 is compared with activity A_2 of a known mass W of salt, of the same ivity as the radioactive salt column before the diffusion ommenced. As the mass W contains fW grammes of the i being investigated, (where f is the ratio of ionic weight the gramme molecular weight of the salt or salt mixture), mass of this ion crossing the boundary during diffusion y be found from the expression

$$Q = fWA_1/A_2 \quad .$$

TECHNIQUE AND APPARATUS

The practical difficulties in obtaining a method for the asurement of the quantity diffused may be summarized follows: (i) establishment of a sharp planar boundary at commencement of diffusion; (ii) assuring that transport ıot effected by convection; (iii) termination of the diffusion hout effect on the total quantity diffused.

The problem of creating a sharp boundary has been solved a "vacuum bubble" technique. The two columns of lten salt to be interdiffused are contained in a sealed, all bore glass tube (Fig. 1), and are separated, prior to the nmencement of diffusion, by a bubble of gas at low ssure. The method of filling the tube is described hereler. The diffusion is commenced by breaking the tip of the thin capillary (see Fig. 1) when the external pressure slowly forces the two columns together until the separating bubble is small enough to detach itself from the walls of the tube and float. The boundary is thus formed at the position of the meniscus of the lower column.

The apparatus for filling the tubes is shown in Fig. 2. The tube is suspended on a fine platinum wire C in an evacuable vessel B, which is heated over most of its length by means of a tube furnace M. The tube may be raised and lowered by means of an external magnet D. The salts with which the tube is to be filled are held in the two-compartment container A, one compartment containing a radiotracer of the species being investigated. The vessel is evacuated and the tube lowered into compartment (1) (containing the non-radioactive salt) of the container. The vacuum is released sufficiently to allow entry of a 5 cm column of the salt. The tube is lifted out of the container and the vacuum further let out until a bubble of gas 1–2 cm in length is forced in. The tube is then transferred to compartment (2) and another 5 cm column of salt is introduced as before. (Lateral movements of the tube are effected by inclining the apparatus slightly

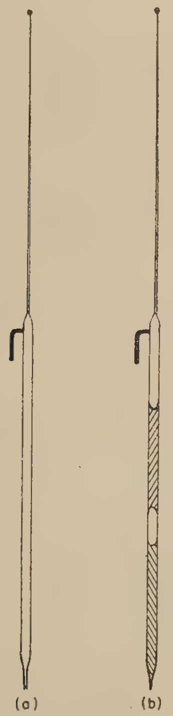

Fig. 1. Diffusion tubes
(*a*) Before filling; (*b*) after filling.

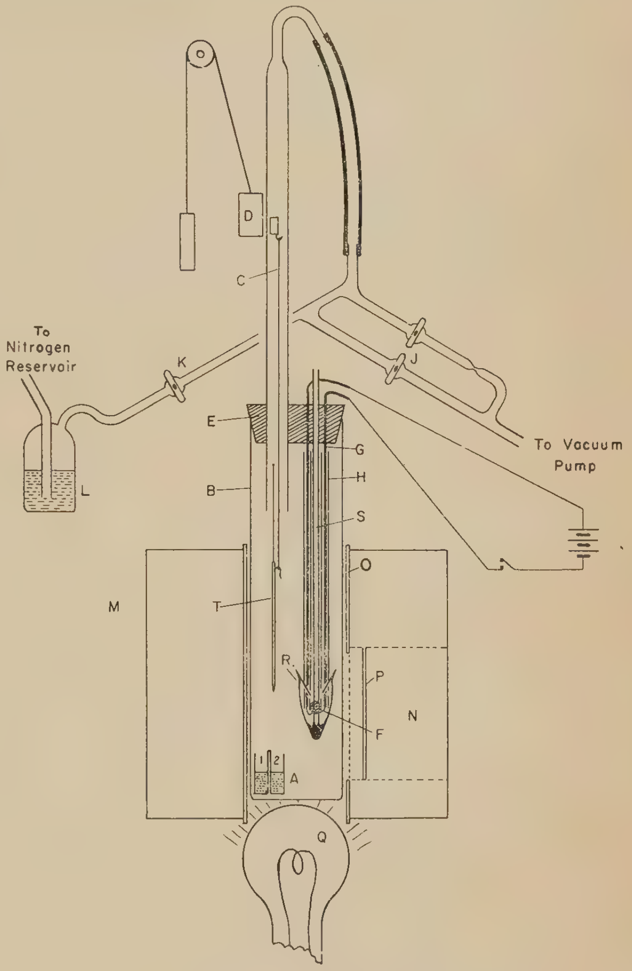

Fig. 2. Apparatus for filling diffusion tubes

A, salt container; *B*, vacuum vessel; *C*, platinum wire; *D*, magnet; *E*, stopper; *F*, platinum spiral; *G*, copper leads; *H*, Pyrex lead casing; *J*, vacuum application taps; *K*, vacuum release tap; *L*, bubbler; *M*, tube furnace; *N*, window; *O*, furnace tube; *P*, Vycor glass plate; *Q*, 60 W lamp; *R*, guide funnel; *S*, thermocouple sheath; *T*, diffusion tube.

to the vertical.) The tube is now sealed by lowering it on to the platinum spiral *F* (electrically heated to 900–1000° C) for 1–2 seconds, and quickly raising it again. This completes the filling operation, and the vacuum may now be completely released.

To avoid convection effects it has been found necessary to carry out the diffusion vertically with a small upward temperature gradient (1–2° C) over the length of the diffusing column. This maintains a density distribution in the melt such that each segment is at a lower density than that below, thus making convection impossible. Lateral temperature gradients are negligible owing to the high heat capacity of the cylindrical aluminium breaking mechanism (D_1 and D_2, Fig. 3).

In ending the diffusion, it is important to avoid any net movement of the salt across the boundary plane, ($x = 0$). A general quenching technique will fail owing to the large contraction during solidification characteristic of molten salts, which causes the formation of considerable pipe cavities and a funnelling movement of the remaining liqui thus forcing (non-diffusive) transfer of salt across th boundary. A quench directed specifically at the boundar constitutes an improvement. However, the method i especially sensitive to salt movement in the vicinity of th boundary, and the errors introduced by use of such a techniqu were found to be significant.

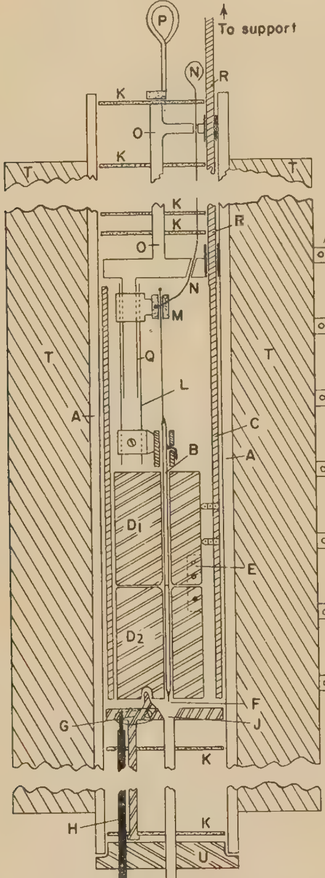

Fig. 3. Arrangement of diffusion tube mounting and breaking apparatus in the furnace

A, furnace tube; *B*, diffusion tube; *C*, stainless steel cylinder; D_1, D_2; hinged sections of solid metal cylinder; *E*, hinge; *F*, hole bored in metal cylinder of close tolerance to tube diameter; *G*, mechanism to bend D_2 about hinge and break tube. Actuated by pushing rod *H*; *H*, thin metal rod; *J*, exit for broken tube lower section; *K*, radiation baffles; *L*, cartridge to support diffusion tube; *M*, mechanism to break capillary. Actuated by pulling wire *N*; *N*, wire leading out of furnace from mechanism *M*; *O*, sliding assembly of radiation baffles; *P*, handle to sliding baffles; *Q*, bayonet plug, projection from sliding baffles; *R*, rail for sliding baffles; *S*, shunts for furnace winding; *T*, furnace lagging; *U*, ceramic plug.

The technique adopted to overcome this problem depend on breaking the tube about a sharp scratch, marked exactl at the position of the boundary. As the breaking may the be done at the temperature at which the diffusion is carrie out, no liquid movements caused by contraction are involved It has been shown that surface tension effectively prevent any escape of the salt during the breaking process, and th salt distribution about the boundary may be exactly preserved

The breaking mechanism is shown in Fig. 3. The diffusio tube *B* slides into a close-tolerance hole bored in an aluminiu cylinder *D*, which is divided in two sections and hinged at The position of the tube in the cartridge *L* is adjusted so th the boundary position will be at the hinge line of the breakin mechanism when the tube is inserted. A mechanism *G* cause D_2 to bend about D_1 when the rod *H* is pushed from outsid the furnace. This action causes a bend-pull stress on th diffusion tube, and results in a uniform fracture. The lowe half of the tube falls out of the furnace through exit *J*. Th section contains the remainder of the originally radioacti column, and it is not required for analysis. The upp section may be withdrawn, and the activity determined b standard radiochemical methods.

PROCEDURE

Diffusion tubes, 6 in. long, are prepared from 3 mm Pyre glass tubing drawn out at one end to a fine capillary 5 i long (see Fig. 1).

The tubes are filled with salt as described above. At th conclusion of the filling operation, the tube is transferre quickly, to prevent freezing, to an auxiliary furnace, which i maintained within ±2° C of the temperature at which t diffusion experiment is to be made. Through a small obse vation port in this furnace, the position of the meniscus o the lower column is noted with reference to a mark on th outside of the tube, using a stereo-microscope with graticule The tube is then cooled, and a broad groove is etched at th boundary position (in order to facilitate the subsequen breaking). A fine circle is now scratched with a diamon point at the bottom of the groove at the exact point indicate by the microscope observation in the previous operation.

The tube is inserted in the cartridge *L* (Fig. 3) and adjustments made so that the boundary mark will come to th correct position in the breaking mechanism. (It has bee found that this position is not critical.) The sliding radiatio baffle assembly (*O*, Fig. 3), is withdrawn from the furnace the cartridge, with tube, mounted on the bayonet-plug typ projection *Q*, and the whole assembly returned to the furnace After allowing ½–1 hour for the necessary equilibrium temperature distribution to be established, the run is commence by drawing on the wire *N*, which causes the mechanism *M* t shear the tip of the capillary. Diffusion is allowed to procee for a period of 5–20 hours, the upper limit depending on th diffusion coefficient and the length of the columns, owing t the necessity of observing the condition that concentratio changes at the extremities are zero. The temperature distribution, measured by a thermocouple (not shown in Fig. 3 outside the aluminium block, is checked once or twice durin the run to assure that an upward temperature gradient ove the whole column is maintained.

o terminate the diffusion, the tube is broken as described ve, when the lower section falls out of the furnace and upper half is withdrawn for analysis.

RESULTS

he method has been tested on a 1 : 1 $CdCl_2 . KCl$ melt, g Cd–115m as tracer.

Time of diffusion (*s*)	$D \times 10^5$ *cm*^{2} *s*$^{-1}$ (469–471° *C*)
$2\cdot \times 10^4$	1·39
2×10^4	1·38
$4\cdot 1 \times 10^4$	1·35
$2\cdot 2 \times 10^4$	1·48

mean value: 1·40
probable error: 2·5%

he present method avoids the crucible rotation and ociated end correction difficulties inherent in the capillary hod. The main sources of error in the measurement lie a small but irreproducible dilution of the radioactive mn during the filling process, and statistical uncertainties he radio-analysis. Removal of the dilution effect should uce the probable error to 1%.

The method is clearly applicable to the investigation of the effect of applied potential differences on the diffusion coefficient, the electrodes being placed beyond the regions where concentration changes due to tracer diffusion take place.

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REFERENCES

(1) Borucka, Bockris, and Kitchener. *Proc. Roy. Soc. A*, **241A**, p. 554 (1957).
(2) Van Artsdalen, Brown, Dworkin, and Miller. *J. Amer. Chem. Soc.*, **78**, p. 1772 (1956).
(3) Berne and Klemm. *Z. Natürforsch.*, 8A, p. 400 (1953).
(4) Delimarskii. *Uspekhi Khimi*, **23**, p. 766 (1954).
(5) Towers, Davis, and Chipman. *Trans Amer. Inst. Mech. Engrs*, **209**, p. 769 (1957).

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n apparatus for visual and acoustical display of electrocardiograms

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[*Paper received* 8 *May*, 1958]

A simple electrocardioscope with a cathode-ray tube and an electrocardiophone are described for use in lectures and during surgical operations. The electrocardiophone can be attached to the cardioscope amplifier and converts the amplified bioelectric potentials into signals of constant audio frequency and of variable intensity.

plifiers with cathode-ray tubes have been used extensively he past for the display and recording of bioelectric poten- s of the heart (electrocardiograms). The mechanical struction of such a device can be simplified considerably t is to be used only for demonstrations in lectures and ing surgical operations, no recordings being then essary. An attempt has been made to simplify also the tronic circuits and the following inexpensive electro- dioscope has been developed.

THE ELECTROCARDIOSCOPE

he electrocardioscope consists (Fig. 1) of the amplifier lves T_1, T_2, T_3, T_4), sweep generator (T_5, T_6), rectifier , T_8) and cathode-ray oscilloscope (T_9). It may be noted t all valves are EF 80 (though any similar pentodes may used without significant changes in the circuit), except two 1 rectifier valves which may also be replaced by any proximately (electrically) equivalent valves.

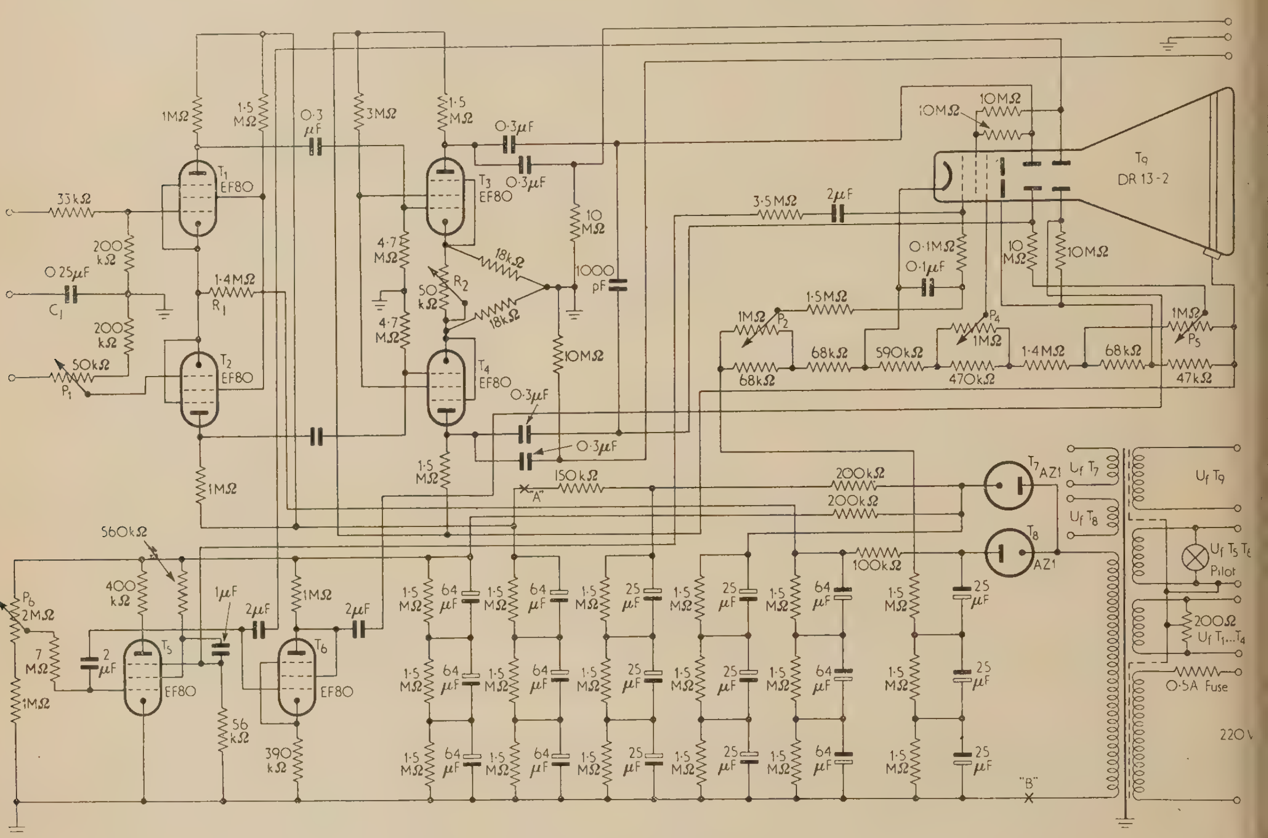
n important feature is the use of a single rectifier for all ts of the cardioscope. Thus a fairly high voltage for the plifier and the sweep generator is available. The rectifier f the Greinacher voltage-doubler type with one end of transformer secondary earthed, giving + and −950 V h respect to earth. The amplifier and the sweep generator supplied by two separated sets of smoothing circuits in ler to prevent a possible interference from the abrupt tage changes in the sweep generator. Extensive use of electrolytic capacitors has been made. Chokes have not been found necessary. Owing to low current drain the ripple developed at the output of the smoothing circuits is low and, at the point *A*, is of the order of a few mV. The AZ 1 rectifiers are not supposed to stand up to a peak inverse voltage of almost 2 kV, but no trouble has been experienced, however, by using them in this circuit though a number of them and of various makes were tried. The transformer primary and the heater for the cathode-ray tube are electrostatically shielded.

The amplifier is of the well established cathode-coupled push-pull difference type. In order to obtain the necessary amplification of about 8 cm/mV with only two pairs of valves, working at 900 V, fairly high plate, screen grid and cathode resistances are employed. The connexion of the cathode resistor R_1 to −950 V provides a very high rejection factor. In fact, when the person under observation is artificially earthed (usually at the right leg) *via* a coupling capacitor C_1 at the amplifier input, there is less than 1 mm mains frequency interference under usual working conditions at the highest amplification. In the presence of very strong disturbing fields which may be caused by the high frequency and similar instruments used during surgical work, the potentiometer P_1 compensates for the residual asymmetry at the amplifier input. The variable resistor R_2 controls the overall amplification. Little effort is necessary to match the pair of valves in the first stage. Among the 6 EF 80 valves installed in the electrocardioscope it is easy to find one pair that matches the heater characteristics, the plate transconductance differences being less important. It might be expected that a sparkover might occur inside the amplifier tubes when switching on the electrocardioscope, owing to the delay in the heating up of these tubes. To prevent it a switch was originally inserted at the point *B*. Tests have proved, however, that no harm has been done to the valves when switching on heaters and h.t. simultaneously, probably due to high time constants of the smoothing circuits.

The time base is of the Miller Transitron⁽¹⁾ type (T_5) combined with a simple phase inverter T_6. Both T_5 and T run with low plate currents. With the potentiometer P the trace speed can be varied from 2 to 6 cm/s. The circu of the 5 in. cathode-ray tube is conventional. The potentio meter P_5 is used for minor vertical shifts of the trace.

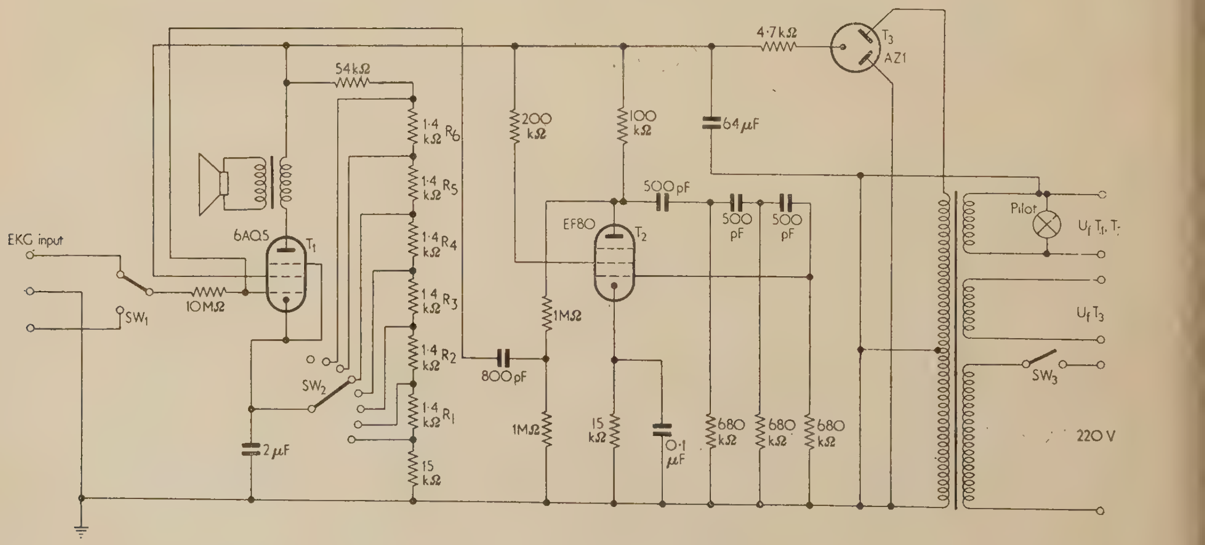
THE ELECTROCARDIOPHONE

Experience has shown that still another monitoring devic is desirable, particularly for use in surgery. In order not t



T1 EF80
T2 EF80
T3 EF80
T4 EF80
T5 EF80
T6 EF80
T7 AZ1
T8 AZ1
T9 DR 13-2
33kΩ
0·25μF
C1
200 kΩ
1·4MΩ
R1
50kΩ
P1
1MΩ
1·5 MΩ
0·3 μF
3MΩ
4·7 MΩ
50 kΩ
R2
18kΩ
0·3μF
10 MΩ
1000 pF
10MΩ
150kΩ
"A"
200kΩ
100kΩ
3·5MΩ
2μF
0·1MΩ
0·1μF
1·5MΩ
P2
P4
P5
68kΩ
590kΩ
470kΩ
1·4MΩ
47kΩ
560kΩ
P6 2MΩ
7 MΩ
400 kΩ
1μF
56 kΩ
390 kΩ
64 μF
25 μF
"B"
Uf T7
Uf T8
Uf T9
Uf T5 T6
Pilot
200Ω
Uf T1...T4
0·5A Fuse
220 V

Fig. 1. Circuit of electrocardioscope



EKG input
SW1
10MΩ
6AQ5
T1
54kΩ
1·4 kΩ R6
1·4 kΩ R5
1·4 kΩ R4
1·4 kΩ R3
1·4 kΩ R2
1·4 kΩ R1
15 kΩ
SW2
2μF
800pF
200 kΩ
100 kΩ
1MΩ
EF80
T2
500pF
500 pF
15 kΩ
0·1 μF
680 kΩ
4·7kΩ
T3 AZ1
64μF
Pilot
Uf T1, T2
Uf T3
SW3
220 V

Fig. 2. Circuit of electrocardiophone

rt the surgeon's visual attention, an acoustical "display" be made that would keep him informed about the heart-rate and the amplitude of voltages produced. A direct er amplification and a loudspeaker do not appear to be od choice because of the low fundamental frequency (of order of 1 c/s) and of relatively low content of higher nonics of the electrocardiogram. Other possibilities have n considered and described. Recently a device has been ribed⁽²⁾ that converts the bioelectric voltages into high uency changes with subsequent mixing of this frequency n a constant frequency and feeding the loudspeaker with resulting beat frequency. Instead of the frequency lulation, considerably simpler amplitude modulation has n used in the electrocardiophone described here.

he electrocardiophone is considered as an attachment to cardioscope of Fig. 1. It consists (Fig. 2) of a *RC* erator (T_2) working at about 1 kc/s and of the modulator . The modulation takes place at the control grid of T_1. two-position switch SW_1 connects either side of the push- amplifier output to the modulator. The plate load of T_1 is the output transformer for a 2 W loudspeaker, the put of which was found adequate. The sound intensity is trolled by the amplifier with the resistor R_2 of Fig. 1. intensity increases with the positive amplitude of the ut voltage. For the negative amplitudes the intensity reases accordingly. The input voltage that is still audible ends quite critically on the value of the cathode resistance . . . R_6. Thus the cathode resistor control SW_2—dulation level control—was introduced. Its function in nexion with the electrocardiogram is shown in the Fig. 3 ch represents what is called the normal human electro- diogram. For high values of the cathode resistor, only ;e *R*-peaks are audible, corresponding to the level I–I. reasing the resistance makes the modulation level rease also and levels II–II and III–III may be reached, king it possible to hear besides the *R*-peaks also the eaks and finally the *P*-, *R*- and *T*-peaks. This feature of cardiophone has been found most useful, as also small nges in the peaks became perceptible.

Though the electrocardiophone has been designed together with the electrocardioscope described, the design is such that it should be useful with any electrocardiograph—or -scope amplifier, providing a high enough amplitude at the input and both polarities is available. Since most modern electrocardiographs use the push-pull technique this should be in general achieved without considerable changes at the amplifier output.

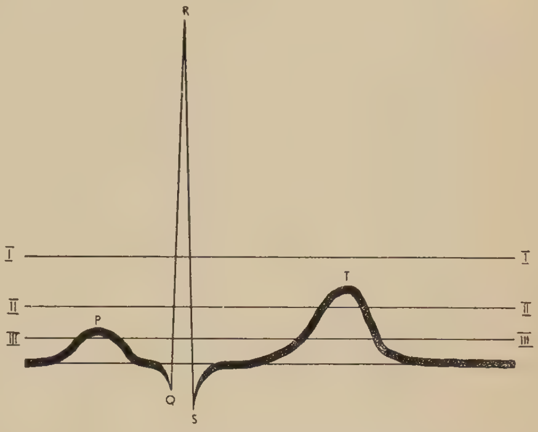


Fig. 3. Normal human electrocardiogram

ACKNOWLEDGEMENT

Thanks are due to Ing. L. Vodovnik for his suggestions during the work.

REFERENCES

(1) Miller, J. M. *Sci. Papers of the Bureau of Standards*, **15**, p. 367 (1919).
(2) Gemant, A. Burch, D. C., and Miller, E. B. *Rev. Sci. Instrum.*, **27**, p. 400 (1956).

A very sensitive relay, able to withstand heavy overloading

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A galvanometer relay is described which consists of a mirror galvanometer with limited deflexion, an optical system, a photoconductive cell, a Wheatstone bridge and a polarized relay. The input is a small d.c. current supplied to the galvanometer coil. The output is the energy available at the switch contacts of the polarized relay. The power amplification, i.e. the ratio between minimum input energy necessary to actuate the relay and maximum output energy available at the contacts of the polarized relay, is, in the simple prototype, 1 : 10^{13}; the figure for a commercially produced version could be much higher. Large input overloading is allowable, e.g. a current 100 000 times greater than the minimum failed to damage the instrument. The instrument described is already quite small (4 × 4 × 6 in.), but improvements in its design could reduce the size still further.

gress in polarized relay development has been towards r more sensitive instruments. This has resulted in so- ed moving-coil relays as now manufactured by several 1s.⁽¹,²,³,⁴,⁵⁾ The power needed to actuate such relays ounts to about 10 μW, their sensitivity of response is ghly 0·2 mA and their maximum allowable input current ut 40 mA. The highest power which may be applied to h instruments is 8 W. Here, therefore, the ratio between maximum output and the input which just suffices to actuate the instrument, the so-called power amplification, is equal to about 800 000 : 1, while the overload capacity, the ratio between the maximum current which may be supplied to the coil of the relay and the minimum current to which the relay will respond, is about 200 : 1.

If both these quantities were appreciably bigger, the relay could be incorporated into many different kinds of measuring instruments. It could be used to give an alarm when activated by very small signals or to drive a servomechanism which would enable the above-mentioned instruments to function automatically. Such a performance can be achieved by putting into practice the principles given below.

PRINCIPLE OF OPERATION

The classic instrument able to function on low currents and voltages is the galvanometer. In the course of time, both sensitivity and robustness have been increased to such a pitch that a modern portable galvanometer with a current sensitivity of $0 \cdot 3 \times 10^{-9}$ A/mm deflexion (i.e. about 1 000 000 times more sensitive than the moving-coil relay under discussion) does not even need to be locked during transport.

Its overload capacity, however, is small. When a certain stability is required, e.g. when the galvanometer must return constantly to zero with a deviation not greater than $\pm 0 \cdot 02$ in./$0 \cdot 5$ mm (length of light beam = 20 in./1 m), its greatest deflexion must not exceed 4 in./100 mm. The reason for this lies not in the electrical but in the mechanical properties of the galvanometer. Let us examine this more closely.

A galvanometer of the type just mentioned (non-lockable) gives a deflexion of $0 \cdot 04$ in./1 mm at a current of $0 \cdot 3 \times 10^{-9}$ A (resistance of the coil 450 Ω). The electrical power taken up by the coil is therefore $i^2r = (0 \cdot 3 \times 10^{-9})^2 \times 450 \text{ W} \simeq 4 \times 10^{-17}$ W. A coil of this size should, however, easily be able to withstand $0 \cdot 4$ W without being overheated and, consequently, damaged. From an electrical point of view, therefore, the current through the coil might well be increased 100 000 000 times without damaging the galvanometer. Mechanically, however, a very different state of affairs prevails: should such a heavy current be supplied to the coil, the latter would receive a rotational impulse sufficiently strong to twist the torsion fibre through several turns. The deformation of the torsion fibre which would result from this would cause a noticeable deviation from zero when the current no longer passed through the coil.

It will readily be seen that this can be avoided quite simply by limiting mechanically the angle through which the coil can turn. Several smooth, non-magnetic, metal pins on either side of the coil, preferably lying in a plane at right angles to the rotational axis and set level with the centre of gravity of the coil, suffice to ensure that the light-spot projected by the galvanometer can sweep through an interval of only a few tenths of an inch.

At very small currents this system operates as a normal galvanometer; the deflexion is proportional to the current and the direction of the deflexion follows the direction of the current. At a previously determined current strength, however, the coil comes in contact with the blocking stops. Thereafter the deflexion remains constant, however much the current increases. This system appears to have a stable zero-setting which is not influenced by repeated overloading.

The limited deflexion galvanometer thus developed must now be transformed into a relay. For this purpose, use is made of a modern cadmium sulphide photoconductive cell. It appears possible, with a suitable choice of the various quantities, to activate a standard commercial polarized relay by means of a photoconductive cell governed by the light spot projected by the galvanometer.

In the simplest case, a photoconductive cell is incorporated in a Wheatstone bridge circuit which is fed by a suitable d.c. source and in which the polarized relay forms the bridge connexion.

It is also possible, with a view to being less dependent on the galvanometer lighting, to use two photoconductive cells forming a Wheatstone circuit with two fixed resistances.

A circuit which has been applied in practice is described below.

PERFORMANCE

General information. In order to test the above-mentioned theory, it was decided to construct a prototype galvanometer relay. A scheme showing the electrical circuitry and the relative positions of the various components is given in Fig. 1, while in Fig. 2 the final result can be seen. The dimensions of the relay shown here are 4 × 4 × 6 in. A commercially-designed form of the apparatus could, however, be considerably smaller.

Galvanometer with limited deflexion. A small coil taken from a portable galvanometer and having a resistance of

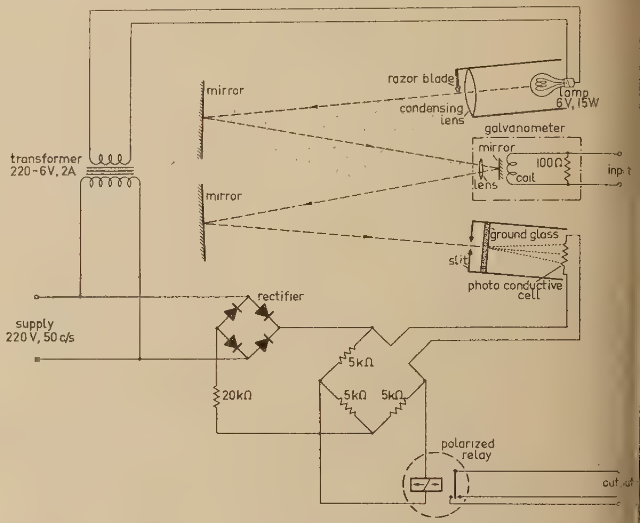

Fig. 1. Galvanometer relay circuits

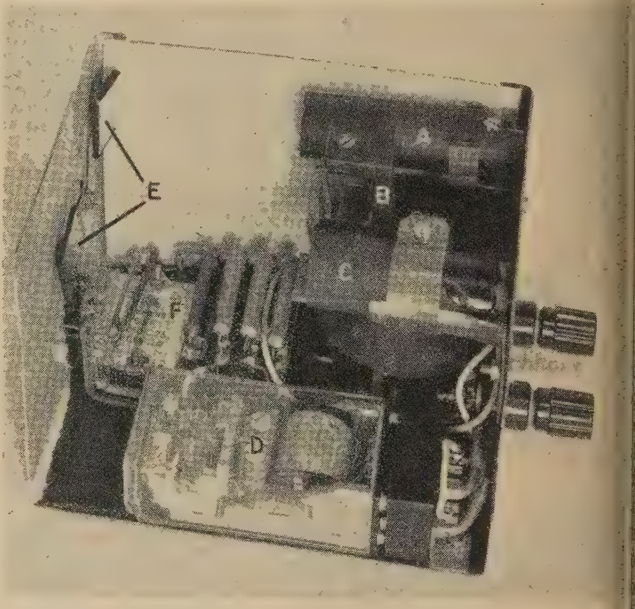

Fig. 2. General view of prototype galvanometer relay

A, tube containing lamp and bearing condensing lense; *B*, galvanometer; *C*, tube containing photoconductive cell; *D*, polarized relay, *E*, adjustable mirrors, *F*, rectifier.

Ω was attached to two torsion fibres, each 20 mm long, suspended between the poles of a permanent magnet. ough the magnet took up much room owing to its ilar shape, it was nevertheless used since the gap between poles was exactly suitable for the purpose. A shunt tance of about 100 Ω was needed to obtain good damping. ne following, therefore, the current through the galvano- er plus shunt will be represented by a replacement tance of 50 Ω. The galvanometer in its new form was set to have a light beam 8 in./20 cm long.

ne sensitivity of this "home-made" apparatus appeared e considerably reduced when compared with the original mercial instrument. A current of about 0·3 μA was needed to give a deflexion of 0·04 in./1 mm, while μA had previously been sufficient (calculated with the e light-beam length). The galvanometer coil was limited s movements by two small brass plates, the edges of which e in contact with the windings of the coil; a workable, ugh not very elegant, arrangement.

s can be seen in Fig. 3, the points of contact were not l with the centre of gravity of the coil, but above it. The ng of the limits was so narrow that the light spot could e no more than 0·2 in./6 mm in either direction.

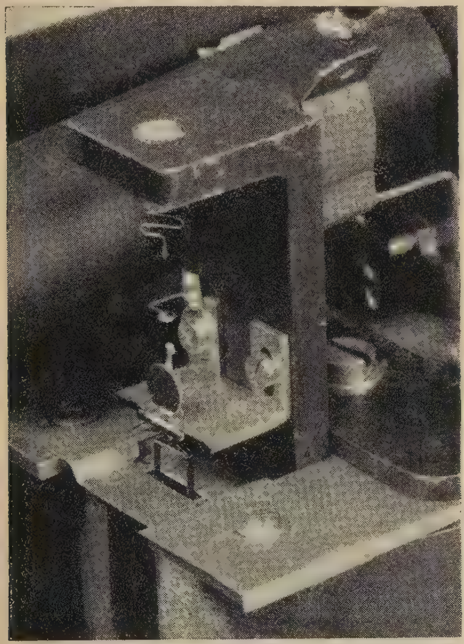

Fig. 3. Detail of galvanometer coil

ptical system and photoconductivity cell. The light rce was a 6 V, 15 W lamp, the light from which was ised on to the galvanometer mirror by means of a con- sing lens. This lens was partially obscured by a razor le. The image of the razor's edge was focused by means a +5 dioptre lens *via* the galvanometer mirror (3 mm neter) on to a slit in front of the photoconductive cell. A ll piece of ground glass was placed just behind the slit give homogeneous lighting of the cell. In order to keep dimensions of the apparatus as small as possible, two istable mirrors were used to reflect the light rays to and n the galvanometer (see Fig. 1 and *E*, Fig. 2).

he image consisted of a circle of light from which a nent bounded by a vertical line had been cut out. The rply-defined edge of this shadow fell across the middle of the photoconductive cell when the galvanometer was at zero. It was later found that a voltage of 4 V at the source gave the right illumination for the cell. A less powerful lamp could also have been used.

Wheatstone bridge and polarized relay. The Wheatstone circuit, consisting of the photoconductive cell and three 5 kΩ resistances, was fed from a 220 V a.c. source *via* a rectifier and a 20 kΩ resistance. The bridge was formed by a polarized relay having a 10 kΩ coil resistance.

The minimum current to which the relay would respond was 75 μA corresponding to a shift of the image across the photoconductive cell of about 1 mm. The light intensity of the source lamp was so adjusted that the resistance of the photoconductive cell was exactly 5 kΩ when the galvanometer was at zero, i.e. when the edge of the shadow fell exactly across the centre of the cell. The contacts of the polarized relay were connected to the output connexions of the apparatus. According to the makers' instructions, the maximum load for this relay is 100 W.

Power supplies. As already mentioned, the Wheatstone bridge was fed directly from the 220 V a.c. supply *via* a rectifier, *F*, Fig. 2.

The illuminating lamp was fed from a 2 A, 220–6 V transformer which, for convenience, was placed outside the box, although sufficient space was available for it inside.

MEASUREMENTS AND BEHAVIOUR

Sensitivity. During calibration of the instrument, it was found that, when connected in the manner described and provided with a light beam 20 cm long, the galvanometer gave a deflexion of ±1 mm at a current of $\pm 0\cdot 3\ \mu$A. At $\pm 1\cdot 5\ \mu$A the coil reached its limits so that increasing the current did not increase the deflexion. There was no zero-shift in the galvanometer after higher currents had been applied.

The minimum current to which the relay responded reliably was $\pm 0\cdot 3\ \mu$A. This corresponds to an input load i^2r:

$$i^2r = (0\cdot 3 \times 10^{-6})^2 \times 50 \simeq 5 \times 10^{-12}\ \text{W}$$

Thus if the power taken at the output is 50 W, the amplification of the relay is about $10^{13} : 1$.

Overload capacity. In order to test the overload capacity, progressively heavier currents were passed through the galvanometer. These caused the coil to hit the stops with a sharp click. On each occasion, however, the system returned to zero. Finally a 1·5 V battery was connected directly to the galvanometer through which a current of 30 mA then passed. Even after maintaining this load for considerable time, not the slightest damage was found. From this it was deduced that it would definitely be permissible to apply a current overload of 100 000 : 1. This was deemed sufficient for the present and no higher supply voltages were therefore tested.

Response time. At the minimum current to which the relay responded reliably, the time which elapsed between the moment when the current through the galvanometer was switched on and the moment when the output contact closed was measured. This time was 0·5 s. At heavier currents this time decreased to about 0·1 s, corresponding to the response time of the polarized relay.

Mechanical behaviour. On several occasions the relay got stuck, i.e. the output contact was not broken when the current in the galvanometer was cut off.

In a more practical construction, therefore, care should be taken to ensure that the windings of the coil do not themselves come in contact with the stops. A suitable attachment should be added for this purpose. It was thought to be too risky to attempt such an alteration, however, and the idea was shelved.

The "home-made" relay described above is rather sensitive to ground vibrations. It is advisable, therefore, to use a hydraulically damped galvanometer system.

Influence of power supplies. As is the case with all Wheatstone bridges, the current passing through the coil of the polarized relay is proportional to the voltage across the bridge. It makes little difference, however, whether the relay responds to a current of 75 or one of 80 μA, so that this effect is not of practical importance. Changing the voltage supplied to the bridge from 100 to 260 V had no noticeable influence on the behaviour of the relay.

The voltage supplied to the illuminating lamp had a greater influence. It was found that at a certain fixed position of the galvanometer mirror, a change in the lamp voltage of ±5% activated the polarized relay. A simple stabilized supply could prevent this.

CONCLUSIONS

With this rather primitive relay a power amplification 10 000 000 times greater than that of the moving-coil relay was achieved while its current overload capacity was at least 500 times greater. However, the limit of the instrument's capabilities have not been reached, since the possibilities of its construction have not yet been fully exploited: the voltage at the illuminating lamp could be increased; the length of the light beam is very short, and so on.

The favourable properties of the relay can be summed u as follows:

(i) the great sensitivity of galvanometer systems;
(ii) the possibility of limiting the deflexion of the galvano meter, enabling the light beam to continue to illuminat the photoelectric resistance and permitting in additio the overload capacity to be greatly increased;
(iii) the optical magnification of the movements of th galvanometer coil and the absence of reaction by th light beam to the coil;
(iv) the transformation of variations in light intensity the cadmium sulphide photoconductive cell int variations in resistance;
(v) the use in the apparatus of comparatively low resi tances (1–10 kΩ), making the application of a norm polarized relay possible.

It is worth remarking, as a final note, that a new rela has recently been described(6) which responds to an inp power of about 10^{-9} W. Its performance therefore roughly between that of the relay mentioned earlier and th of the prototype described above. No data are know concerning its overload capacity.

REFERENCES

(1) Legallais, V. *Rev. Sci. Instrum.*, **14**, pp. 51–52 (194
(2) Isle, D. E. S. *Instrum. Practice*, **9**, pp. 339–341 (195
(3) Electro Methods Ltd. *J. Sci. Instrum.*, **32**, p. 194 (19
(4) Lockwood, E. H. *Machine Design*, **27**, pp. 219– (1955).
(5) Rinke, J. F. *Machine Design*, **27**, pp. 160–170 (1955
(6) Assembly Products Inc. *J. Sci. Instrum.*, **34**, p. 373 (19

Image intensifier for the electron microscope

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An image intensifier is described in which a thin layer of selenium is placed in the electron microscope. The imaging beam causes the selenium to become conducting and potential restoration is provided by an auxiliary scanning beam which produces a television display signal. The device is extremely sensitive and useful images can be obtained with electron microscope beam current densities of the order of 10^{-11} A/cm^2.

In an earlier paper by one of the authors(1) the possibilities of intensifying the electron microscope image were discussed; the desirability for so doing is well known. It was pointed out, however, that the image on the fluorescent screen is already limited by quantum noise in the electron beam. In spite of this, intensification is very well worth while if only to eliminate the need for dark adaptation. The present paper describes some initial results of experiments aimed at achieving a practical intensification system.

The method incorporates a low velocity scanned image tube in the electron microscope on the principle of the "Vidicon,"(2) using amorphous selenium as the sensitive material. The resistivity of amorphous selenium is normally very high but is reduced when irradiated with high energy electrons. In the experimental arrangement the deposit of amorphous selenium (*A*, Fig. 1), 15 μ thick, is supported on a thin (6 μ) plastic membrane (e.g. Melinex, a synthetic resin sheet by Imperial Chemical Industries Ltd.) stretched over support ring, the Melinex being coated on each side with thin aluminium film (*B* and *C*).

The free side of the selenium film is scanned in a standar television raster by an electron gun *F*, which stabilizes th free surface of the selenium to the potential of the electro gun cathode. The rings *D* and *E* are so arranged as to giv a potential distribution between the electron gun and th selenium of such a shape that the scanned electron beam fa normally on the selenium surface, and also to assist reducing effects due to stray electrons. The signal plate backing the selenium film is biased positively to about 300 with respect to the electron gun cathode, so that when th selenium becomes conducting a current tends to flow acro the selenium film raising the free side (side facing gun *F*) a positive potential. On each scan this surface potenti is lowered again to that of the cathode, and the charg deposited by the beam induces a signal in the signal pla which is passed to an amplifier. The signal thus produce will be proportional to the induced conductivity and hen ie electron current density in the microscope image. · amplification the signal is passed to a conventional ision display tube on which an intensified image is ayed.

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ie operation of the intensifier relies on the well-known omenon of electron bombardment induced conduc- ,(3,4) whereby it is possible for a high energy primary ron to create of the order of 1000–5000 secondary ge carriers when absorbed in a layer of selenium and effectively increase the conductivity of the selenium. the conduction current density discharging the film l be several thousand times the imaging beam current ity. The limiting current density giving a usefully bright e on the fluorescent screen in the electron microscope is t 10^{-11} A/cm². (Brightness about 8×10^{-5} lamberts) kV.) The corresponding induced conduction current ity of, say, 2×10^{-8} A/cm² would discharge a 20 μ selenium layer (capacity approximately 250 pF/cm²) everal volts in $\frac{1}{25}$ second. Thus adequate sensitivity ld be available to give a useful signal at current densities v those at present giving usefully bright images on the n. Quantum fluctuations in the primary beam should ar visible in the intensified image for image point areas ss than about 1000 μ² for frame periods of $\frac{1}{25}$ second. means the intensifier should be rather more sensitive the fastest photographic plates now available for ron exposure.

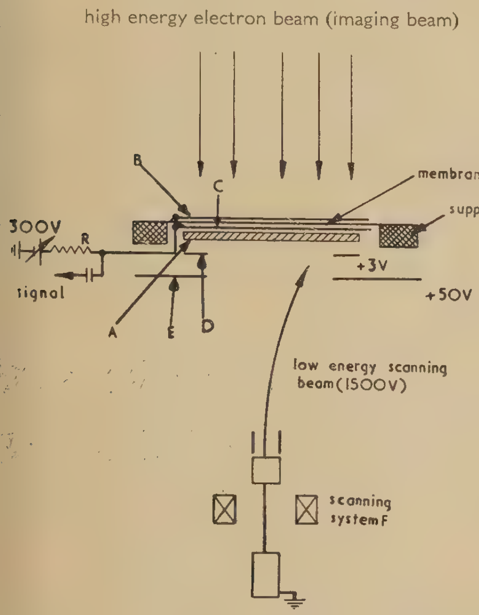
high energy electron beam (imaging beam)
B
C
membrane
support ring
300V
R
iignal
+3V
+50V
A
E
D
low energy scanning beam(1500V)
scanning system F

Fig. 1. Schematic design of intensifier

g. 2 is a photograph taken on the display tube of an intensified image of a standard electron microscope grid, the grid squares having approximately 2·2 mm sides at the layer. The beam current density in the squares was 10^{-11} A/cm² at 60 kV. The definition in this early experiment is limited by the number of lines in the raster but is of the order of 100 μ, i.e. comparable to that of the fluorescent screen.

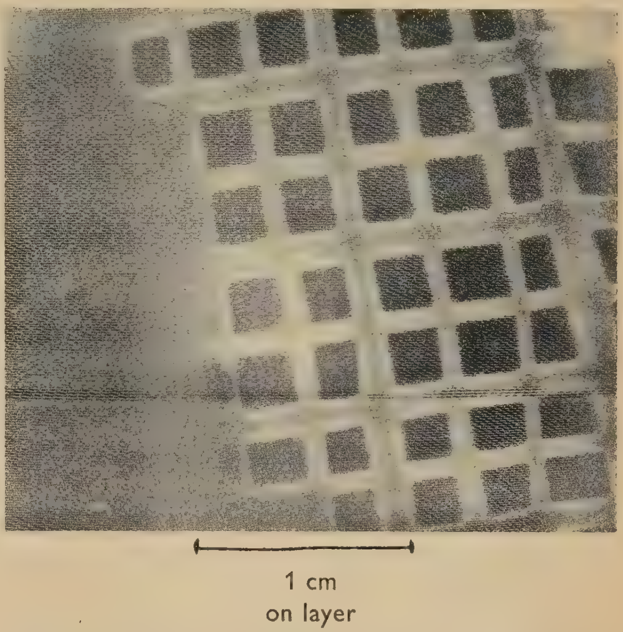

Fig. 2. Intensified image of grid (2·2 mm squares) photographed on a display tube screen. Current density 10^{-11} A/cm²; 60 kV

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The work described in this paper was carried out at the Associated Electrical Industries Research Laboratory, Aldermaston.

REFERENCES

(1) Haine, M. E. *Les Techniques Récentes en Microscopie Electronique et Corpusculaire* (Centre National de la Récherche Scientifique), Toulouse, 1955, p. 59 (Toulouse: Eduard Privat, 1956).

(2) Weimer, P. K., Forgue, S. V., Goodrich, R. R. *R.C.A. Rev.* (p. 306) (September 1951).

(3) Spear, W. E. *Proc. Phys. Soc.* [*London*] *B*, **69**, p. 1139 (1956).

(4) Pensack, L. *Phys. Rev.*, **79**, p. 171 (1950).

Laboratory and workshop notes

low-temperature resistance thermometer using p-type gallium arsenide

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urements of Hall coefficient and resistivity on samples of copper doped p-type gallium arsenide have indicated that the impurity atoms are all deionized at temperatures below about 25° K.(1) At lower temperatures the material exhibits impurity band conduction(2) with an activation energy of about 0·0017 eV. The sensitivity of a resistance thermometer may be defined as $T/R \, . \, dR/dT$ where R is the resistance in ohms and T the absolute temperature in degrees Kelvin. A valuable feature of copper doped gallium arsenside as a thermometric material is the nearly constant sensitivity of about 2·5 over the range 2 to 25° K.

For the thermometers copper-doped gallium arsenide, having a resistivity of about 0·6 Ω cm at room temperature, was chosen. From it single crystals of dimensions 1 by 1·5 by 3 mm were cut and prepared in the following manner. The surfaces of the crystals were ground with fine carborundum then washed in toluene, after which the ends of the specimens were copper-plated in a cyanide plating bath. To improve the electrical contact between the crystal and the copper the specimens were heated in vacuum to a temperature of about 300° C for a few minutes. Diffusion of the copper into the gallium arsenide could be observed quite clearly, and when the process had proceeded sufficiently the copper changed colour to a dark brown. Subsequent tests showed that the contacts were non-rectifying and of resistance less than 0·1 Ω at room temperature. The final arrangement of the thermometers is shown in section in Fig. 1. The plated contacts *AA′* were soldered to the leads on a small metal-to-glass seal *B*, similar to that used in the construction of crystal diodes. After cleaning the surface of the crystal with alcohol and toluene, it was coated with collodion for protection and insulation. Additional protection was provided by the copper can *C* soldered to the rim of the metal-to-glass seal at the top and open at the lower end to admit helium gas from the cryostat, thus improving the thermal contact between the thermometer and its surroundings.

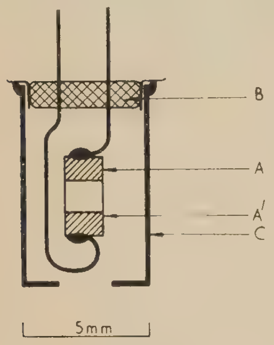

Fig. 1. Sectional diagram of gallium arsenide resistance thermometer showing arrangement of connexions

The resistivity of the thermometer material at 4·2° K was found to be about 2·5 × 10^5 Ω cm. Measurements showed, however, that the resistance of the thermometers at this temperature was slightly dependent on the applied voltage, even though the heat dissipation was kept as low as 10^{-8} W. By operating the thermometers from a constant voltage source of 100 mV observations of the current were conveniently made on a Scalamp galvanometer down to the lowest temperatures.

The gallium arsenide thermometers were calibrated by means of a helium gas thermometer and a calorimeter, cooled by liquid helium, which could be maintained at any temperature between 2 and 77° K. The accuracy of temperature measurement with the gas thermometer was 1%. Good thermal contact between the gas thermometer bulb and the gallium arsenide thermometers was achieved by soldering them to a copper block and filling the calorimeter to atmospheric pressure with helium gas. Fig. 2 shows the results obtained for two specimens with the above arrangements. The current in the gallium arsenide thermometers is plotted on a logarithmic scale as a function of reciprocal temperature measured with the gas thermometer. It will be noticed that at the highest temperatures the slope of the curves increases rapidly, corresponding to ionization of the p-type impurities. Below 20° K the slope of the curves is fairly constant and corresponds to an activation energy of 0·0017 eV. Calibra tion measurements were repeated several times at intervals a few days to provide a check on the stability of the thermo meters. No departure from the original curves greater tha the error in temperature measurement could be detected.

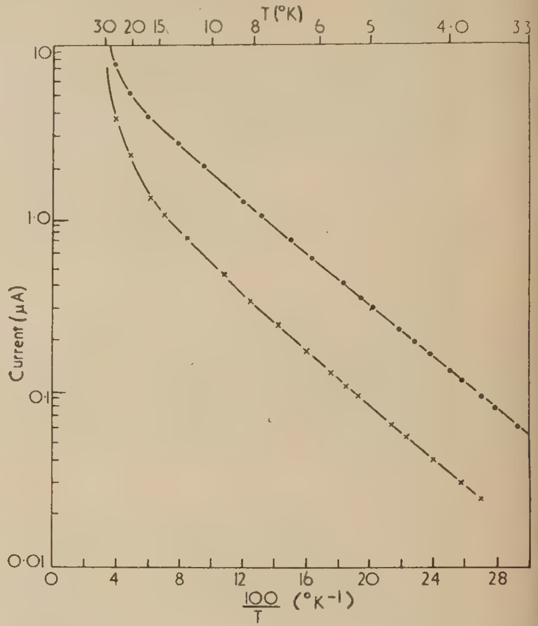

Fig. 2. Calibration of gallium arsenide resistanc thermometers. Variation of current with constan applied voltage of 100 mV plotted as a function of reciprocal temperature

The effect of light on the thermometers was investigat and they were found to be photoconductive, especially at th lowest temperatures. It is therefore important to screen t thermometers from light in order to obtain reliable reading

Owing to the low mobility of the carriers$^{(1, 2)}$ the magne resistance effect is small. At 4·2° K the conductivity of t above specimens increased by only 0·4% in a magnet field of 10 kilo-oersteds. This corresponds to an error temperature measurement of about 0·0015° K.

The two thermometers for which calibrations are sho have been in regular use for over six months, during whic time no change has been observed in their characteristics. A liquid helium temperatures, where the temperature could b accurately determined from measurements of the heliu vapour pressure, the long-term reproducibility has bee found to be better than 0·5%. In this work no attempt ha been made at very great accuracy of temperature measur ment such as is obtained from the germanium thermomete described by Kunzler, Geballe and Hull$^{(3)}$: the main emphas has been placed on ease of construction and operation.

The author wishes to thank Dr. A. C. Rose-Innes f providing some of the above data and Dr. O. Simpson f his assistance in the preparation of the manuscript. Ac nowledgement is made to the Admiralty for permission publish this note.

REFERENCES

(1) EDMOND, J. T., BROOM, R. F., and CUNNELL, F. *Report of the Meeting on Semiconductors*, p. 1 (London: Physical Society, April 1956).
(2) HUNG, C. S. *Phys. Rev.*, **79**, p. 727 (1950).
(3) KUNZLER, J. E., GEBALLE, T. H., HULL, G. W. *Rev. Sc Instrum.*, **28**, p. 96 (1957).

ttachment for measuring reflexion interference spectra the Beckman DK2 ratio-recording spectrophotometer

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a thin transparent film mounted on a reflecting base ved by normally reflected light, an interference spectrum ained. From the wavelength values at which minima in such a spectrum it is possible to estimate the thickness he film, using the relationship:

$$y = [(2n - 1)\lambda/4\mu_\lambda] - C$$

μ_λ is the refractive index of the film at a wavelength λ, nteger and C the difference in phase changes on reflexion air/film and film/reflector surfaces expressed as a path . Since μ_λ and C both depend upon the wavelength incident light, appreciable errors can occur when μ_λ umed constant and C ignored, as is frequently the case. ng anodically-formed oxide films on tantalum, Charlesby Polling* have shown that where a second parameter is linearly related to film thickness is available, it is ole to calculate the film thickness absolutely. This is d out by measuring the wavelengths at which interce minima occur at normal incidence for a number of ent films, and also the shift observed in the position of inima when the angle of incidence is increased.

attachment shown in Fig. 1, which fits into the cell artment of the Beckman DK2 ratio-recording spectrometer, has been of particular use in these laboratories

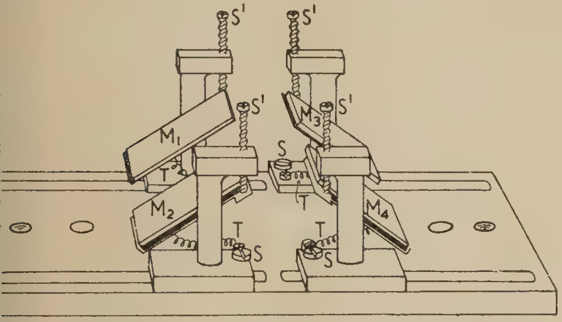

Fig. 1. Diagramatic representation of attachment

neasurements of the oxide film thickness on anodized s using the approach indicated above. The use of a rophotometer such as the type DK2 enables results to btained more rapidly, and over a larger wavelength (0·3–2·0 μ), than with manual instruments. The ility of this instrument has permitted measurements on samples of surface area $\frac{1}{4} \times \frac{1}{8}$ in. not having the r finish normally required, and also on samples rsed in liquid.

e optical path traversed in the cell compartment is shown g. 2. The mirrors M_1M_2 reflect the beams entering the artment on to the aluminized mirror (as reference) and ample, from whence mirrors M_3 and M_4 reflect on to the tor. The mirrors are adjustable both in position and of incidence by means of screws S and S' (Fig. 1) the attachment is in the cell compartment. The al compartment lid is replaced by a blackened plate having two $\frac{1}{2}$ in. diameter holes, each being immediately above the centres of the respective reference and sample channels.

The attachment may be set for approximately normal incidence by first moving all the mirrors to the centre of the base plate, and adjusting the angles of M_1 and M_2 until the reflected light is immediately above the centres of the light paths inside the compartment (as shown by a strip of transparent paper placed across the top of the compartment). An aluminized mirror is now placed across the compartment top and mirror M_3 adjusted to give minimum slit width and mirror M_4 to give maximum transmission. Minor sideways deflexions of the light beams by the mirrors may be readily corrected if the mirrors are mounted on a thin layer of plasticine, thus allowing correction by pressure in the appropriate side of the mirror. For these adjustments light of wavelength 5460 Å is used. The lid may now be placed in position and spectra measured.

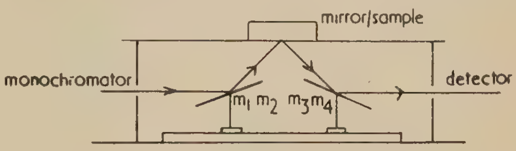

Fig. 2. Optical path traversed in cell compartment

The mirror supports are prevented from rotating by means of tenons beneath their bases and are locked in position by means of clamping plates riding on wider slots beneath the tenon slot. Contact between the mirror support plates and the screws S' is maintained by means of tension springs T attached between the support plates and the mirror supports. By moving the mirror supports towards the outer edges of the base plate it is possible to increase the angle of incidence to 30° with the sample as described, and to 60° when the sample is lowered into the compartment (on a suitable mounting). Since the light enters the compartment horizontally, its angle of incidence on to the sample is $(90 - 2\theta)$ where θ is the acute angle between mirror M_2 and the horizontal. For other than near normal incidence, the angle θ may be adjusted outside the instrument and the mirror supports for M_1 and M_2 moved along the base plate, when in the compartment, until the reflected light, as shown by transparent paper, passes through the positions normally taken up by the sample and the reference mirror. The remaining adjustments are as described previously.

The author wishes to thank the Chairman of Tube Investments Ltd. for permission to publish this note.

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[*] Charlesby, A., and Polling, J. J. *Proc. Roy. Soc. A*, **227**, (1955).

A method of completely filling capillary tubes with mercury for diameter determination

By G. F. Whitty, A.R.M.T.C., Defence Standards Laboratories, Department of Supply, Melbourne, Australia

[*Note received* 12 *May*, 1958]

In many fields of research, difficulty has been experienced in determining very accurately the diameters of capillaries in the range 1 to 0·5 mm. The mercury-content method is not easy to apply satisfactorily because of the difficulty of completely filling the bores with mercury. Hence a filling technique, developed during measurements on a pressure type viscometer with a set of stainless steel capillaries of diameters down to 0·48 mm and of 40 to 1 length-diameter ratio, will be of interest.

First, one end of the capillary was closed by a glass disk *A* (Fig. 1) retained against the end of the capillary by making use of the thread on the mounting sleeve, and then mercury was introduced into the capillary through a very finely drawn glass tube *C* (Fig. 2) of external diameter 0·3 mm. When filled, the other end of the capillary was sealed by a second glass piece *B* (Fig. 1). It was important (to avoid air being trapped during filling) for the tip of the tube to be inserted right to the bottom of the capillary and then gradually withdrawn as the mercury entered, care being taken to keep the tip always below the surface of the mercury. Finally a slight excess of mercury was run in so that the meniscus projected beyond the top end before closing the capillary. The glass end pieces allowed the mercury to be readily inspected for trapped air. The mercury contained in the capillary bore was emptied into a tared vessel and weighed, and the length of each capillary accurately measured.

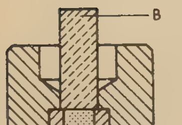


Fig. 1. Method of sealing ends of capillary tubes

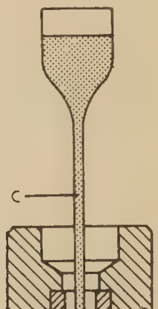


Fig. 2. Method of filling capillary tubes

Repeat measurements of the mean diameter on four capillaries ranging from 1·14 down to 0·48 mm did not differ by more than 0·5 μ and the value of a single determination was estimated to be within an accuracy of 1 μ.

This technique has been used also to determine the volume of the capillary portion of a MacLeod gauge.

An X-ray tube target current stabilizer

By R. S. Crisp, B.Sc., Grad.Inst.P., Department of Physics, University of Western Australia

[*Note first received* 14 *May, and in final form* 14 *July,* 1958]

In the operation of a soft X-ray spectrometer, where a photomultiplier is driven around the Rowland circle to detect th diffracted radiation, it is essential that the X-ray output from the target remain constant during the scanning of an emissio band.

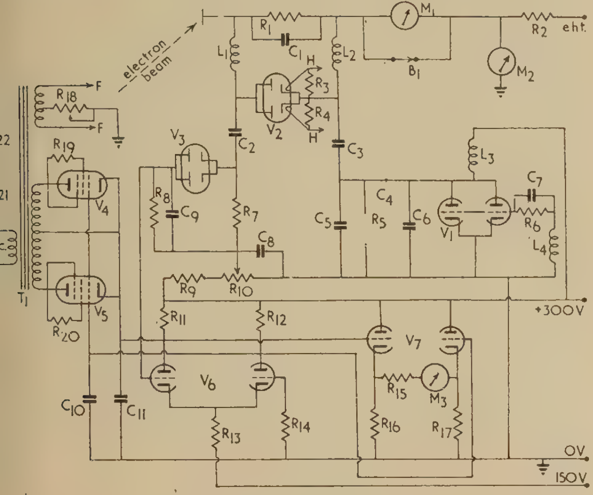
In the present instrument,(1) the target was run at +4 k and the electron gun filament at near earth potential, the tota emission from the filament being stabilized by means of circuit similar to that given by Elmore and Sands for a ionization gauge.(2) With the total filament emission constan to better than 1% and with the observed fluctuations in gu focusing potentials and target voltage less than ½%, tar current fluctuations of 5% and corresponding changes i X-ray intensity were observed. This effect is attributed t changing vacuum conditions in the source chamber an changing insulating films on the gun electrodes. These effect change the currents collected by the electrodes, the amount o gas scatter and the beam current reaching the target. Henc although the total filament emission was held constant, th target current could and did fluctuate. The stabilizer show in the figure was accordingly devised to permit sampling th beam current actually reaching the target at +4 kV an applying an appropriate signal to the emission circuit at nea earth potential.

Radio frequency at 500 kc/s from the oscillator V_1 is pas through the diode V_2 *via* the capacitors C_2, C_3. Bot capacitors are insulated to 10 kV d.c. and isolate the samp circuit, which is at the target potential, from the rest of t unit. The bias on V_2 is determined by the electron bea current flowing in the resistor R_1. The r.f. signal passed b V_2 is rectified by the detector V_3 and the d.c. volta developed across R_8, C_9 depends upon the bias on V_2 an hence on the target current.

The detector output is amplified by the difference amplifi V_6 which controls the bias on the tubes V_4, V_5. These tw tubes act as a variable load on the transformer T_1 which ha the resistances R_{21}, R_{22} in series with its primary windin An increase in target current results in a decrease in bias o V_4, V_5. Their increased plate current causes an increase i the primary current of T_1. The correspondingly larg potential drop across R_{21}, R_{22} results in a smaller voltag appearing across the transformer primary and hence acro the secondary winding *FF* which powers the gun filamen This causes the required reduction in target current. Th action of these load tubes is also described in Ref. (2). T balanced nature of the amplifier V_6 and the method coupling to V_4, V_5 result in this portion of the circuit bei insensitive to changes in the +300 V and −150 V supplie

For a 1 mA change in target current a signal of 280 would appear on the grids of V_4, V_5 and for the transform turns ratios given this would cause a current change approximately 3·0 A in a filament operating at 9 A a 1·7 V. The stabilization factor has not been measu directly, but the observed target current fluctuations a considerably less than 0·5% at 5 mA.

The control R_{10} varies the stabilized target current fro zero up to 8 mA. Larger currents can be handled decreasing R_1 or preferably by increasing the output volt of the oscillator, the limit being set by the peak inver rating of the diode V_2. In the present case the output some 75 V r.m.s. Filaments operating at different nts and voltages require appropriate adjustment of the ormer turns ratios. The best operating condition is or which R_{22} is set to the largest possible resistance and ias on V_4, V_5 is between 10 and 40 V. For a fixed g of the "current adjust" control R_{10} the setting of the tat R_{22} is varied to give this bias as indicated on the ım tube voltmeter V_7, M_3. The combined effects of me constants R_1C_1, R_8C_9, $R_{11}C_{11}$, $R_{12}C_{10}$, increase the nse time sufficiently to prevent oscillation due to the vely long thermal time constant of the filament.



Circuit of stabilizer

15 kΩ
50 kΩ, 20 W
= 5·6 MΩ
500 kΩ
20 kΩ
8 kΩ
500 kΩ
300 kΩ
100 kΩ potentiometer (current adjust)
$_{12}$ = 250 kΩ
150 kΩ
100 kΩ
1 MΩ
$_{17}$ = 300 kΩ
10 kΩ potentiometer (self bias adjust)
$_{20}$ = 100 ω
50 ω, 25 W
1100 ω, 200 W

sistors 1 W unless otherwise ified
0·02 μF
= 1000 μμF ins., 10 kV d.c.
= 100 μμF

C_6 = 220 μμF
C_7 = 1000 μμF
C_8 = 0·02 μF
C_9, C_{10}, C_{11} = 0·01 μF

L_1, L_2 = r.f.c. 500 mH
L_3, L_4 = 500 kc/s oscillator coil

M_1 = 0–15 mA (target current)
M_2 = 0–10 kV (target voltage)
M_3 = 1–100 V, 100 μA movement

B_1 = "Press to read" button. Normally closed and insulated to 10 kV

FF = connexions to gun filament
HH = 6·3 V heater winding insulated to 6 kV

T_1 = Primary 250 V. Secondary 6·3 V C.T. 350 V–0–350 V

V_1 = 12AU7
V_2 = 6AL5 (socket, etc., insulated to 4 kV. Shield conn. plates)
V_3 = 6H6
V_4, V_5 = EL34
V_6, V_7 = 6SL7

ie capacitor C_1 and the resistor R_2 in series with the ut of the target high tension supply are to protect the e V_2 from destructive inverse voltages when poor vacuum itions in the X-ray tube cause arcing from the target high instantaneous voltages across R_1. This was parırly necessary in an earlier version of the stabilizer h used a germanium diode as V_2.

is important to note that the sampling circuit output nds on the total current flowing in R_1 and hence includes s due to leakage currents in the target insulation and ı the water cooling pipes. With 4 ft lengths of capillary ıg for the water cooling the total leakage current is some at 4 kV and fluctuations in this, which the stabilizer cts for by changing the beam current, are too small to etected as fluctuations in the observed X-ray intensity.

ACKNOWLEDGEMENT

is work has been carried out during the tenure of a Postgraduate Research Studentship from the Australian Atomic Energy Commission.

REFERENCES

(1) FISHER, P., CRISP, R. S., and WILLIAMS, S. E. *Optica Acta* (in the press).
(2) ELMORE, W. C., and SANDS, M. *Electronics*, p. 396 (New York: McGraw-Hill Book Co. Inc., 1949).

A triode-connected pentode with stabilized anode current

By B. C. Cox, B.Sc., Ph.D., A.R.I.C., Flintshire Technical College, Connah's Quay, nr. Chester

[*Note received* 10 *June*, 1958]

In electronic circuits with d.c. connexions, drift often results from variations in the heater supply voltages. The usual method of removing this source of drift is to supply the valve heaters from a stabilized power supply; this note describes an alternative method.

In the triode of Fig. 1 the grid is maintained positive with respect to the cathode by battery *B* of voltage *V* and internal resistance R_B, the actual potential appearing at the grid being $V - i(R + R_B)$ where i is the grid current. If the cathode temperature falls, its emission, and consequently the grid current, will decrease, causing the grid to assume a more positive potential. Provided that *R* and *V* are large enough for a small change in grid current to produce a large change in grid potential, the increased grid potential will raise the emission and restore the anode current to practically its original value.

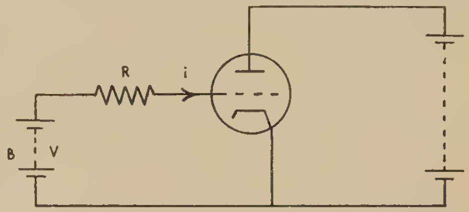


Fig. 1. Diode connected triode with stabilized anode current

This method of anode current stabilization has been applied to a pentode type 6K7G as shown in Fig. 2. The normal control grid is connected through *R* to the supply voltage of 225 V, and is used for anode current stabilization. The screen grid is connected as the control grid, and the suppressor grid connected to the anode to give the electrode assembly triode characteristics. The effect of heater voltage on the anode current is plotted as curve (1) in Fig. 3, together with a comparable curve (2) for a normally connected triode, type 6J5G. Curve (1) shows that the anode current is

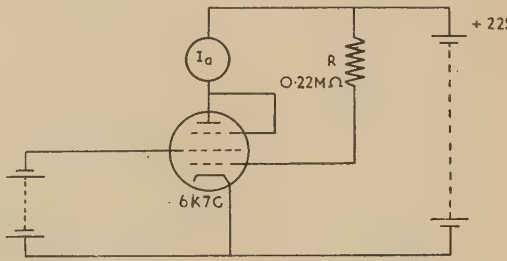


Fig. 2. Triode connected pentode with stabilized anode current

virtually independent of the heater voltage in the range 4–8 V, for a pentode connected in this way.

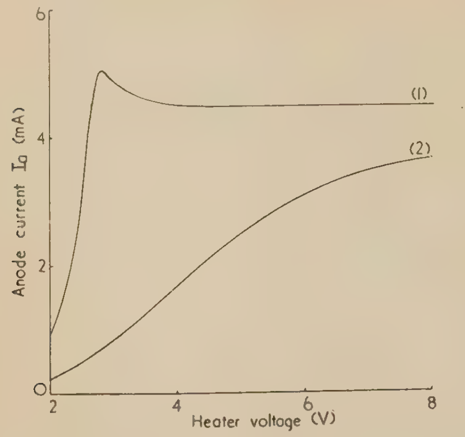


Fig. 3. Variation of anode current with heater voltage for (1) a triode connected pentode with stabilization, and (2) a normally connected triode without stabilization

Typical operating characteristics of the pentode type 6K7G under such conditions have been determined, and are given in the table below.

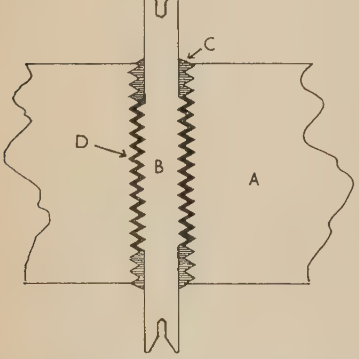
V_a(V)	V_{g2}(V)	I_a(mA)	g_m(mA/V)	*u*	I_{g1}(mA)
225	−3·0	3·8	0·5	20	1·1

A high-pressure electrical lead-in

By D. F. Gibbs and M. Jarman,* H. H. Wills Physics Laboratory, University of Bristol

[*Note received* 21 *July*, 1958]

The construction of seals for electrical connexion to the interior of high pressure vessels, for use above about 4000 atm, presents a considerable problem, since no insulators are available with mechanical properties as good as those of metals. The cone-in-cone principle$^{(1)}$ is often used, the insulator then being largely in compression; if only a fine wire needs to be sealed, the method of Gugan$^{(2)}$ and Lazare$^{(3)}$ is convenient. The method to be described here is in some sense a combination of these two. It consists of a male and a female screw thread of normal Whitworth form, except that there is rather more clearance than usual. The space between is filled with the insulating material (see figure).



High-pressure lead-in (not to scale)

A, pressure vessel wall; *B*, conductor; *C*, resin applied to *B* during assembly; *D*, resin applied after assembly.

Since the elastic moduli of the metal parts are higher than those of the resin insulator used, the thrust is sustained by many turns of the insulating helix, enabling higher pressures to be used than with a single cone of comparable dimensions. As with the cone principle, the system may be designed so that complete failure of the insulator does not result in ejection of the conductor until the metal parts are also severely deformed.

Seals have been made using a nominal $\frac{3}{16}$ in. B.S.F. thread, of length $1\frac{1}{2}$ in. The female thread was to size, formed with a commercial nut tap. The male thread was cut on a precise screw-cutting lathe. Its core diameter was 0·02 in. under size, and the thread depth and angle were almost exactly equal to those of the female thread. This resulted in a thickness of insulator of about 0·005 in. In order to locate the conductor, small cylinders of resin, about $\frac{1}{4}$ in. long, were cast on to the ends, which were first machined down to core diameter. The conductor was then replaced in the screw-cutting machine, carefully re-registered on the existing thread, and full-size threads cut in the resin.

After cutting small slots parallel to the axis in the locating pieces at the ends of the conductor, the latter was screwed home carefully into the outer. All being well, it was now supported only by its ends, and there was no metal-to-metal contact. Liquid resin was then forced through one of the slots into the space by means of a vacuum pump, and allowed to polymerize. The resin used both for the locating pieces and the main insulator was Marco resin type SB.28C (a cold-setting polymerizing resin supplied by Messrs. Scott Bader and Co. Ltd.) with 16% by weight mica flour as a filler. Before applying it, the metal parts were carefully degreased.

Seals made in this way were found to have a capacity of about 100 pF, and an insulation resistance greater than 1000 MΩ. There was no electrical or mechanical failure up to pressures of 4500 atm. Greater hydrostatic pressures were not available, but the conductor of such a seal was subjected, in a hydraulic ram, to a thrust sufficient to cause plastic deformation of the conductor, again without failure.

Owing to the fine clearances, the seals are not easy to make, but they have considerable advantages, and they do not leak at low pressure.

We are grateful to Mr. G. Grainger for his skill in constructing these seals.

REFERENCES

(1) Bridgman, P. W. *The Physics of High Pressures*, 2nd Ed., p. 51 (London: G. Bell & Sons, 1951).
(2) Gugan, D. *J. Sci. Instrum.*, **33**, p. 160 (1956).
(3) Lazare, F. *J. Phys. Radium*, **14**, p. 213 (1953).

Improvements in photographic printing of electron micrographs

By D. M. Hall, M.Sc., Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Note first received* 10 *March, and in final form* 14 *July*, 1958]

The fine structure on electron micrographs can only be recorded on prints if the photographic enlarger has sufficient resolving power. If, for instance, the resolving power of the electron microscope is 50 Å and the specimen is magnified 5000 times then the plate or film used for recording must resolve structure 0·001 in. apart. The photographic enlarger will require a resolving power of the order 4000 lines/in. to ensure that structure 0·001 in. apart on the plate or film appears sharp to the eye when enlarged, say, 20 times.

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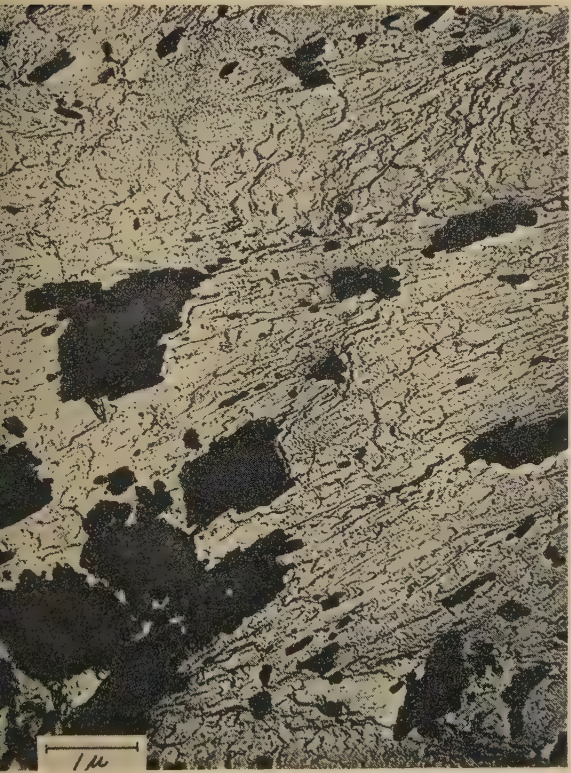
* Now at the Department of Zoology, University of Bristol.

1. Electron micrograph of a carbon replica of human enamel



3. As Fig. 1, but using an over-dense unsharp mask

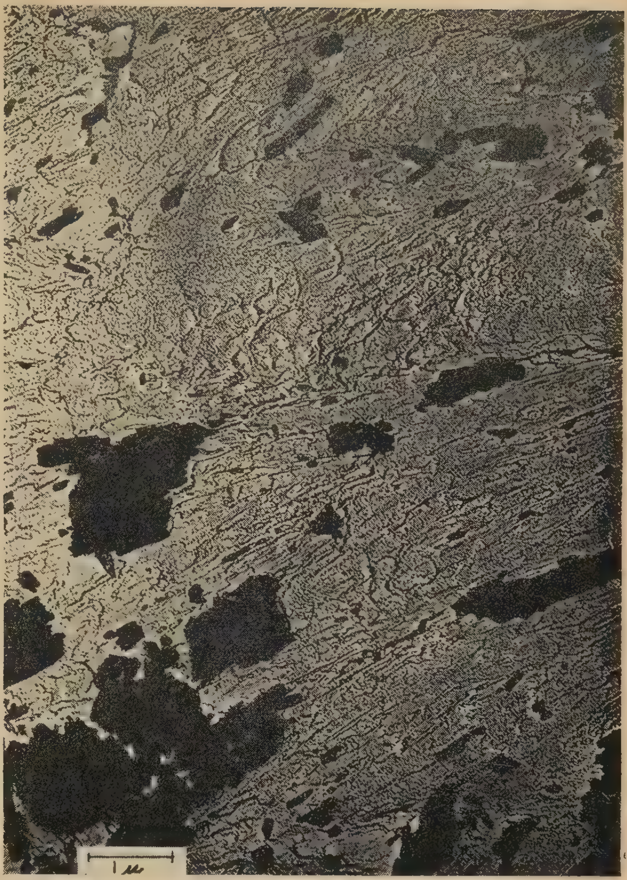


Fig. 2. As Fig. 1, but using an unsharp mask of correct density

The commercial enlarger in our laboratory was modified to produce these results by the following means:

(*a*) The light source consisting of a 230 V lamp was replaced by a 6 V compact filament lamp with a filament length of approximately $\frac{1}{8}$ in.
(*b*) The spherical condenser lens was replaced by an aspheric type to minimize aberrations and utilize the properties of the compact filament to full advantage. The combination of compact filament and aspheric lens increased the intensity of projected light and this assists identification of the area to be enlarged and reduces exposure time.
(*c*) The projection lens was replaced with an f4·5 lens with a resolving power of the order of 5000 lines/in.
(*d*) The base and column of the enlarger were secured to the building to prevent relative movement.

There are occasions, however, when we wish to record fine detail in the immediate vicinity of the grid bars or other electron opaque objects and it is then necessary to employ dark room aids, such as the unsharp mask technique, to control halation. The unsharp mask technique consists of superimposing a low density unsharp mask or positive on the contrasty negative so that the large-scale contrast is reduced without reducing the contrast of the fine detail.

The unsharp mask is produced by placing the negative emulsion side down, above a sensitized plate but spaced from it by a small distance, e.g. 0·035 in., the thickness of a photographic plate. A diffuse light source consisting of a 60 W lamp with a piece of ground glass in front of its holder is used to expose the mask. The light source is held by hand approximately two feet above the negative and moved in a roughly circular path of one foot diameter to produce the right order of unsharpness for electron microscopy. Exposure and development which produces a mask density of the order of 20% of the original negative has given best results, but it is usual to make two masks and choose the mask which removes halation without overcorrection.

An enlargement is made by mounting the negative and unsharp mask with their emulsion surfaces adjacent but just separated by thin spacers of, say, 0·010 in. thickness. The mask is placed above the negative and is moved gently into position so that features on the mask are superimposed symmetrically on the corresponding features on the negative.

Fig. 1 is a direct print from a carbon replica of human enamel and shows some enamel crystals attached. Fig. 2 is a print of the same negative but using an unsharp mask, and Fig. 3 is an example of overcorrection with a mask that is too dense.

An improvement to the multi-stage impulse generator

By W. A. Smith, Atomic Weapons Research Establishment, Foulness, Essex

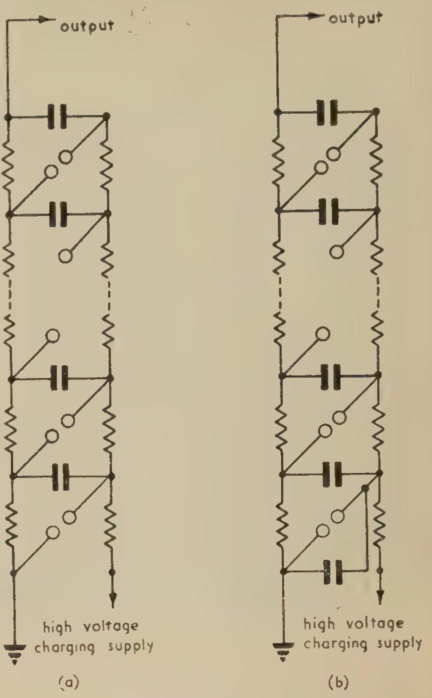
[*Note received* 10 *June*, 1958]

Difficulty is sometimes experienced in the operation of multi-stage impulse generators because of the lowest spark gap continuing to arc after the generator has been discharged. This trouble is most frequently experienced when the impulse decay time is adjusted to times of the order of a millisecond, and is particularly troublesome with the miniature impulse generators which are convenient laboratory sources of high voltages of the order of 30 to 150 kV. (Such impulse generators can often be constructed of readily available components and, as they only require direct current supplies at voltages of the order of 5 to 10 kV, there is no necessity for expensive corona shielding.)

The continuous arcing of the lowest spark gap can be prevented by connecting a capacitor directly across it, as shown in the figure. This capacitor also improves the performance of the generator in two other ways.

(i) The irradiation of the other spark gaps by ultra-violet light from the lowest gap is made much more intense at the instant before they are required to break down. In practice, this modification makes the tripping of the generator more consistent and permits its operation over a wider range of voltages without adjustments being necessary in the spark gap spacings.

(ii) It permits the time required to charge the generator to be reduced, by allowing a reduction of the impedance of the high voltage source to be made, without the arcing in the lowest gap recurring.



(*a*) Standard version of multi-stage impulse generator: (*b*) improved version

The connexion of a capacitor in this position will not affect the output waveform of the generator to any great extent, since the voltage across a spark gap falls to a low value when breakdown occurs. The size of the capacitor is not at all critical and it can conveniently be made the same as the other capacitors in the generator.

NOTES AND NEWS

Correspondence

The magnetic spectra of some ferrites

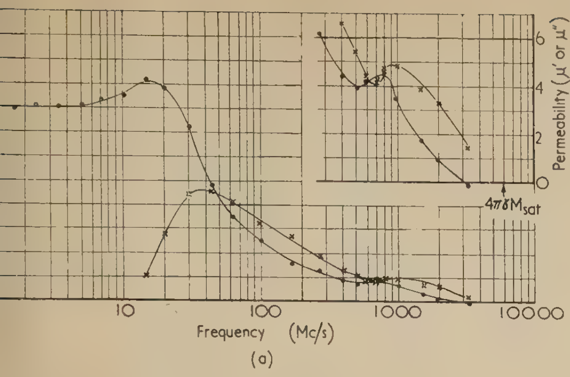
Measurements have been made of the complex initial permeability ($M = \mu' - j\mu''$) of ferrites in the range 1·0–3300 Mc/s, special attention being given to the accuracy and reproducibility of the results, which are in general about ±1%. Important features observed include:

(1) The spectra all show two more or less distinct parts, and in some cases there are two maxima in the permeability. This is particularly evident in the example (*a*) illustrated in the figure. The form of the lower-frequency region depends largely on the method of preparation of the specimen (compare (*a*) and (*b*) in the figure), but the upper region appears to be mainly a function of the composition (compare (*b*) and (*c*) in the figure). This supports the theory of Rado and others according to which the r.f. initial permeability of ferrites is due to two separate mechanisms.(1)

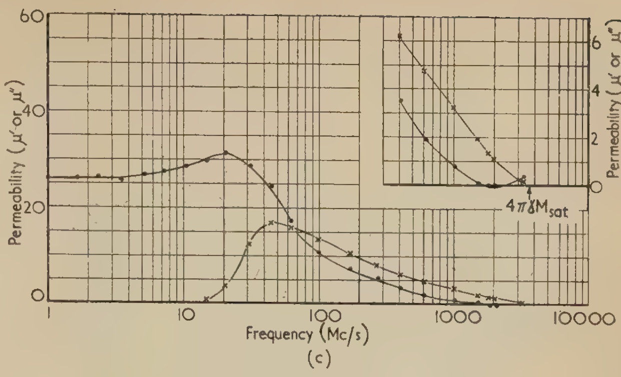
(2) No fine-structure is apparent.

(3) The imaginary component of the permeability approaches zero at a frequency given by $4\pi\gamma M_{sat}$ with $\gamma \simeq 2{\cdot}8$ Mc/s per oersted. This is consistent with the theory of Polder and Smit(2) and also with Rado's identification of the high-frequency dispersion region as the one due to domain rotation.

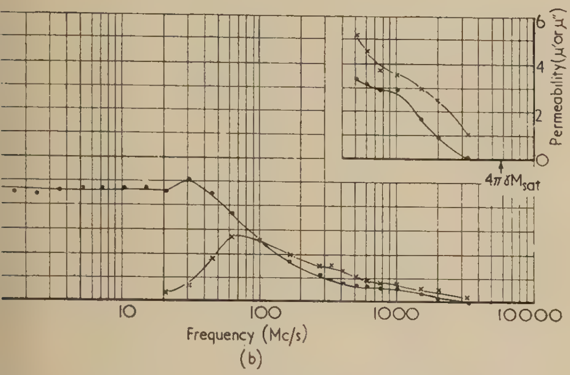
All the measurements were made using co-axial resonators which were of three types. In the range 1–60 Mc/s non adjustable lumped-capacitance resonators were used, and the change in resonance frequency caused by the insertion of the



(a)



(c)



(b)

Spectra of complex permeability for three ferrite materials

● μ'; × μ''.

(*a*) Nominal metallic content
$Mg_{1\cdot47}Mn_{0\cdot165}Fe_{2\cdot0}$ fired at 1400° C.

(*b*) Nominal metallic content
$Mg_{1\cdot47}Mn_{0\cdot165}Fe_{2\cdot0}$ fired at 1300° C.

(*c*) Nominal metallic content
$Mg_{1\cdot47}Mn_{0\cdot165}Al_{0\cdot375}Fe_{1\cdot625}$ fired at 1300° C.

was measured by a method using two signal generators ; a frequency ratio of about 15 : 1. A crystal mixer ces signals at both the sum and difference frequencies. may be used to excite the resonator, and small changes frequency can be made with accuracy by varying the frequency generator. In the range 250–3300 Mc/s an able re-entrant cavity was used, as previously bed.$^{(3)}$ For the intermediate points it was necessary e fixed quarter-wave co-axial resonators with the dyne arrangement.

permeabilities were calculated in terms of the measurable parameters of the resonators and no arbitrary methods of calibration or "fitting" were required.

Research Laboratories of
The General Electric Co. Ltd.,
Wembley, England.

E. A. Faulkner
J. F. Werner

[21 April, 1958]

REFERENCES

(1) Rado, G. T., Wright, R. W., and Emerson, W. H. *Phys. Rev.*, **80**, p. 273 (1950).

(2) Polder, D., and Smit, J. *Rev. Mod. Phys.*, **25**, p. 89 (1953).

(3) Faulkner, E. A. *J. Sci. Instrum.*, **34**, p. 514 (1957).

New instruments, materials and tools

ditor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

ie MS4 compound. Holiday and Hammerdinger, Ltd., l Ardwick Green North, Manchester, 12.

ie MS4 compound is a smooth homogeneous silicone with the consistency of petroleum jelly. It has good cal properties, water repellent characteristics and does elt. It can be applied by brushing or wiping, or may rayed when dispersed in a solvent such as carbon loride, trichlorethylene or aromatic solvents.

s stated that the silicone repels moisture and makes es water repellent and so prevents moisture seepage leads, maintains high surface resistivity under con- s of high humidity, prevents corona, protects insulation orona effects and gives materials increased arc resistance. so claimed that it acts as an anti-oxidant when applied stic and synthetic rubber insulation, and keeps natural ynthetic rubber components flexible. It is further in a lubricant for rubber cables being drawn through it, and allows cable harnesses to be more easily assembled. Finally it is stated to prevent corrosion and sticking of machined surfaces and gaskets.

The detailed electrical properties are given as follows: volume resistivity, up to 200° C, 10^{12} Ω cm; permittivity, between 100 c/s and 10 Mc/s, 2·8; power factor, between 100 c/s and 10 Mc/s, 0·001; electric strength, at 10 mil., Min. 500 V/mil.

Digital display unit. Counting Instruments Ltd., 5 Elstree Way, Boreham Wood, Hertfordshire.

This unit comprises a system of lenses whereby a figure or letter is projected on to a screen by means of twelve lamps. The main advantage of this method of display is that the image always appears in the same plane, thus giving a wide angle of view. Units can be banked together to give, for example, the read-out on a digital voltmeter. The dimensions of a single unit are $2\frac{5}{8}$ in. high, $1\frac{9}{16}$ in. wide and $5\frac{13}{32}$ in. long; the displayed figure measures $1 \times \frac{5}{8}$ in. The standard model has provision for projecting the digits 0–9 and two decimal points; other models are being developed showing letters and signs with provision for either coloured characters against a black background or a coloured outline to a white character.

Low-frequency phase meter. Airmec Ltd., High Wycombe, Buckinghamshire.

The phase meter type 206 has been designed to enable measurements of gain, attenuation and phase shift to be made on any four-terminal network operating in the frequency range 20 c/s to 100 kc/s. Phase is indicated directly on a 6 in. meter having four scales, and gain or loss values are indicated by the difference between two attenuator settings. Input signals are connected to the instrument *via* two cathode follower probes having input impedances of 12 MΩ. Measurements are made by adjusting the attenuators in each channel to give standard meter deflexion. The phase displacement is then indicated directly on the meter when the selector switch is set to read phase difference. The difference of the attenuator readings is the gain or loss between the two input channels. The range of input level on either channel is 1 to 1000 mV, so that insertion loss or gain up to 60 dB can be measured. The circuit consists of two identical amplifiers incorporating cathode follower inputs and calibrated attenuators. Each amplifier is followed by an identical trigger circuit which generates a pulse at the point where the signal voltage is zero. These pulses are then passed to the metering circuit where they determine the relative duty cycles of two valves forming a flip-flop circuit. The difference of these duty cycles is indicated on the meter as phase measurement. Since the instrument indicates the difference in phase where the two signals have zero value, the instrument is relatively insensitive to wave-form distortion. An accuracy of 2° is claimed for phase angle measurements over the frequency range 100 c/s to 20 kc/s; outside these limits the accuracy is 5°. The attenuators in each channel consist of a 50 dB attenuator having 10 dB steps and a 10 dB slide-wire. An accuracy of 0·2 dB is claimed for each unit.

Microscope immersion oil with thixotropic properties. Cooke, Troughton and Simms Ltd., Haxby Road, York.

Liquids used for microscopic immersion have a tendency to flow into parts of the instrument where their presence is undesirable. It is possible to reduce this effect by increasing the viscosity of the medium, but it remains troublesome, especially where large areas are required to be maintained in immersion contact.

A non-drying thixotropic immersion fluid has now been developed which is free from the above defect since it gels when left at rest at room temperature, but becomes fluid immediately when stirred, shaken or otherwise disturbed. The refractive index matches that of a standard microscope cover-glass ($\mu_d = 1 \cdot 524$ at 20° C) and tests indicate that the medium has suitable optical properties for most routine microscopical applications.

It can be applied in relatively large quantities and left for a lengthy period without flow taking place.

Measuring relays. Leland Instruments Ltd., 22 Millbank, London, S.W.1.

The Sensitact relay, manufactured by Brion Leroux et Cie of Paris, is based on a spring-suspension galvanometer unit. The relay consists of a moving-coil system complete with scale and pointer, to which has been added a moving contact. On each side of the contact are arranged two adjustab contacts which are accessible beneath a transparent du cover and are adjustable over the full range of the scale. Th relays are fully shielded and are available in sixteen mode having coil resistances ranging from 2·5 to 7500 Ω, and wit full-scale deflexion current ratings from 10 mA to 20 μA. I the case of the most sensitive model, the minimum change control power necessary to make or break the contact is the order of 0·05 μW. The relay contacts have a powe handling capacity of 200 mW. Each model has a scale one hundred divisions and is available in an end-zero and centre-zero form.

Neutron moisture gauge. Nuclear Enterprises (G.B.) Ltd Bankhead Medway, Sighthill, Edinburgh 11.

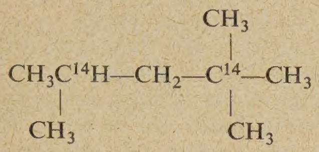
The NE 8401 moisture gauge has been developed for accura *in situ* measurements of the moisture content of a lar variety of materials under field conditions. It is claimed th accuracies of the order of 2% are possible, the effec sampling volume being from 30 to 60 cm diameter, depend on the moisture content of the material. The probe un contains a radium-beryllium source of fast neutrons. Whe the probe is placed in the given medium, the neutrons fro the source are scattered by the nuclei of atoms in the mate and lose energy until the neutron energy approaches th thermal energy of the atoms. Hydrogen is particularly effec tive in slowing down the fast neutrons. A boron trifluo counter, which is sensitive only to thermal neutrons, is u in the detection head and records a counting rate depen on the concentration of hydrogen atoms in the mate The thermal neutron count is thus a measure of the mois content of inorganic materials. For organic materials co taining bound hydrogen it is necessary to subtract a ba ground count. The probe unit is connected by a 100 ft s braided cable to a portable scaling and power unit whic registers the count rate from the detector. The probe un is of stainless steel 50 cm long and with a diameter of 3 c It contains a 10 mc source of radium-beryllium, a spe enriched boron trifluoride slow neutron detector and transistorized amplifier. During transportation, the prob unit is protected by a 20 lb lead shield, which provides a adequate protection against radiation hazard. The prob unit itself weighs less than 4 lb. The control unit, powere by accumulators giving approximately 1 A at 6 V, supplie the high voltage for the probe and contains a scaler syste with reset and a timer. The moisture content of an inorgan sample can be obtained directly from the counting rate b means of a calibration curve supplied with the instrumen provided no elements of high neutron cross-section ar present; special methods of interpretation are needed for thes Organic materials can be examined provided the boun hydrogen content is constant and is allowed for.

Radioactive hydrocarbon. Research Specialites Co., 2 South Garrard Boulevard, Richmond, California, U.S.A.

Iso-octane-C^{14} (or 2,2,4-trimethyl pentane–2,4,-C^{14}) is no available from this firm who claim to have made the fir synthesis of the compound with the C^{14} labelling. Th material is expected to have wide application in hydrocarb and petroleum research involving combustion and kine and mechanism studies. The problems in synthesis of th compound will be understood from the information that the eight-step production run, using barium carbonate-C for introduction of the radioactivity, a maximum volume 2 ml. of liquid is handled. The makers claim that the pr s free from both chemical and radiochemical impurities. ysis by gas chromatography shows it to be identical spectro-grade 2,2,4-trimethyl pentane. Specific activity present stock is 2·86 mc/mM. Higher specific activities 5 mc/mM can be provided on request.

ıer C^{14} labelled hydrocarbons are available from this information about which will be sent on request.

-octane C^{14} has the following structure



$$CH_3C^{14}H{-}CH_2{-}C^{14}(CH_3)_2{-}CH_3 \quad (CH_3 \text{ on } C^{14}H)$$

ically-heated glass. Young and Power, Branksome Court, 21 The Avenue, Bournemouth West.

ectrically-heated glass has been developed in Switzerland. made of specially toughened and non-splintering glass viching extremely fine resistance wires, one tenth the ıess of a human hair and practically invisible to the l eye. The amount of heat given off per square foot e varied according to requirements.

th this glass it is claimed that there is no optical deflexion eration in colour. Phenomena of reflexion, deviation ıromatic distortion are eliminated owing to a special ss of manufacture. The light absorbed is only 1% than that absorbed by an equal thickness of ordinary This loss is so small that it is not noticeable to the ı.

e glass is stated to be instantly de-misting and de- ng and is invaluable for observation panels, instrument s, etc., where the differential between inside and outside eratures and the degree of relative humidity render such liable to be obscured.

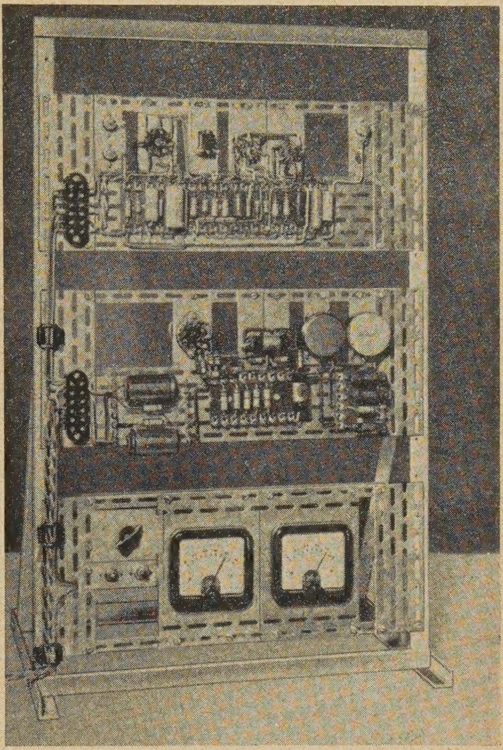
ıtors. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

e indicators are designed to display a selected number ear, illuminated figures without any mechanical move- in the indicator, and with only a low voltage electrical y. Two types of indicator are made, one is edge- inated, the other is a projection device.

line indicators are primarily designed for panel mounting an be assembled in banks so that, as many decades as red are displayed in adjacent windows. The line of s appears as it would be written or printed. There is a e of white or green light and continuous or dotted rals. In the edge-illuminated type, each unit (one e) comprises a stack of ten Perspex plates each engraved a numeral from 0 to 9. The order in which the plates acked can be varied, and the plates can be engraved signs, symbols, letters or figures as required. The ction type are complementary to the edge-illuminated ıtors and have been produced for situations in which a al display requires to be viewed either from a con- ble distance or from a wide angle. The numbers are cted on to a diffusing screen by a simple optical system.

onic chassis kit. Shandon Automation and Electronics Ltd., 6 Cromwell Place, London, S.W.7.

Rapikon system is designed to enable "on-off" circuits rapidly assembled or modified. The system consists of r plates, slotted plates and girders, and a rack. The r plates are specially punched to hold valve-holders, tiometers, switches, terminals, plugs and sockets or meters. They are assembled in positions as required in a frame made from slotted plates and girders. Each holder plate has a pronged end for sliding on a slotted plate, the other end being fixed with a nut and bolt. The pronged end allows tag panels and wiring to overlap the holder plate, thus shortening leads and simplifying assembly. The slotted plates and girders referred to above can be assembled in a variety of ways to suit individual requirements. The slotted plates can also be used to take components such as tag panels, chokes, transformers or terminal blocks for which holder plates are not required. Several chassis, constructed as described, can be mounted as separate units in the rack, which is 25⅞ in. high and 15½ in. wide.



Examples of chassis construction with Rapikon kit

Insulation flash tester. Gresham Transformer Group Ltd., Hanworth, Middlesex.

Over a period of years an instrument for flash testing insulating materials has been developed by this firm. It has appeared in three models and it is claimed that the last one Mark III, contains remedies for all the limitations in the other two types. The final model, it is stated, is as near perfect design as is possible.

The principle of operation is quite simple. A voltage between 500 and 2500 V, as required, is applied to the circuit under test by means of two shock-proof probes. If a fault is found a short-circuit is indicated, and the testing voltage is automatically switched off. If necessary the faulty insulation may be burnt out to locate the fault.

The instrument operates on 200 to 250 V, 50 c/s supplies. The voltage of the testing output rises in steps of 500, 750, 1000, 1500, 2000 and 2500 V a.c., according to the position of the selector switch on the front panel.

The quick-acting circuit-breaker is connected to the input circuit and trips at approximately 2·5 A input current. This circuit-breaker has withstood industrial production line testing at the rate of 1000 tests per day for months on end.

When it is desired to burn the fault so that, for example, smoke will indicate its position, the "burn-fault" switch will bring into the circuit certain current limiting resistances which will prevent the circuit-breaker from tripping. Safety is ensured by a thermostat, which opens the circuit-breaker before the limit of the safe operating temperature is reached. Pilot neon lights indicate when the input and output circuits are alive and the whole panel has been much improved on previous models in both general appearance and legibility.

Despite the high voltage of 2500 V maximum, the instrument is stated to be completely safe. The input and output circuits are electrically isolated. The test probes are of polished ebonite with retractable shields so that the live probes cannot be bared until they are actually applied to the circuit under test. The probes are connected to the instrument by single-core heavy flex, and the whole tested to 10 000 V. The probe shields have Mycalex tips, which ensure that there is no flash-burning of the ebonite.

Instrument for growing single crystals of semiconductors. Edwards High-Vacuum Ltd., Manor Royal, Crawley, Sussex.

Of vital importance in the manufacture of transistors is the production of semi-conductor crystals of controlled purity, a process normally carried out either in an inert atmosphere or under vacuum. The Speedivac silicon crystal pulling unit is basically a flexible unit, and where necessary it can be modified by the user with the minimum effort and expense to suit individual requirements peculiar to the art of crystal pulling. It is eminently suitable for both development work and full-scale production.

The pumping system comprises a 6 in. oil diffusion pump capable of a final vacuum of better than 5×10^{-6} mm of mercury, and having a baffled speed of more than 300 l./s. A 9LP6 baffle and isolation valve is mounted above the diffusion pump which is backed by a 15 ft^3/min rotary pump. The rotary pump outfit is mounted separately on the floor and connected to the diffusion pump by flexible connexion to minimize vibration. A small 1 in. oil diffusion pump is also fitted to the equipment for evacuating the "screen tube" surrounding the crystal pulling rods, thus ensuring that no oil or grease contaminates the growing chamber. The whole pumping system is complete with isolation and control valves and protective devices. Vacuum measurement in the plant is provided by Pirani and Penning type vacuum gauges which are mounted on the top of the cabinet housing in a complete instrument panel. The same panel also contains the instrumentation for the other electrical equipment which is used on the plant.

The remainder of the equipment comprises a crystal growing chamber with hoist and rotating mechanism for raising and rotating the crystal during its growth. The growing chamber is approximately 2 ft high and is provided with pumping and loading ports and viewing windows. The hoist and rotating mechanism is contained in a flanged metal casing, approximately 16 in. high, and this is mounted directly on to the cover of the main vacuum chamber. The crystal pulling rod is arranged for variable rates of rotation and pull. The entire apparatus is housed in a stove-enamelled metal cabinet, the dimensions of which vary depending on whether the rotary pump is mounted externally or internally. The cabinet is 3 ft 6 in. high × 3 ft 8 in. wide × 3 ft deep and the overall height of the plant to the top of the crystal mechanism is almost 7 ft.

Photographic and direct-reading spectrograph. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London N.W.1.

This Triple Medium Spectrograph is a photographic and direct-reading spectrograph combined and will therefore be of particular use in laboratories where there is a large amount of routine work to be done, but where there are also some qualitative and quantitative analyses that fall outside the scope of the direct-reading instrument.

As its name implies, it has three measuring heads. One of these is for photographic analysis and can be used for the same type of work as the medium quartz spectrograph. The other two measuring heads can be set up for the automatic analysis of non-ferrous metals, oils, soil and similar materials. The spectrum required is chosen by switching mirrors. Each direct-reading head accommodates twelve photomultipliers and will give quantitative analysis of up to eleven elements in about two minutes. These direct-reading heads can be set up for two completely different analyses or for the analysis of two different groups of elements in the same alloy. For the latter application it is normal to use two separate sparkings—one for the minor elements using one bank of photomultipliers, and the other for trace elements using the other bank of photomultipliers; though in certain restricted circumstances it is possible to analyse up to twenty-two elements with one sparking.

It is not necessary to buy both direct-reading heads at the same time. The instrument can be supplied in the first place with only one of these attachments and the second can be fitted at a later date, when required.

Resin solvent. Oxley Developments Co. Ltd., Oxley, Ulverston.

A powerful solvent is available which makes possible the reclamation and salvaging of electronic components from rejected units sealed in epoxy or polyester resin casings. In the potting, embedding and encapsulation of electronic systems it sometimes becomes desirable or necessary to reclaim the embedded unit owing to the functional failure of the system. By the simple immersion and soaking of the faulty unit in the solvent, it is claimed that the components may be readily removed.

It is a non-inflammable, neutral solvent combination of low toxicity and is extremely easy to use. The potted unit containing the items to be reclaimed is placed in a suitable container provided with a cover. Closed containers are recommended as an economy measure to avoid excessive evaporation. A sufficient quantity of the solvent to completely cover the items to be treated is poured into the container and the cover put on. They are then allowed to soak for from eight to twelve hours. If very thick sections are involved, a longer immersion period may be necessary. After the requisite soaking it will be found that the disintegrated resin may be removed by brushing or rubbing. It is then quite a simple matter to replace the faulty component and the assembly is ready for re-potting. The solvent is suitable for re-use after removal of the resin particles by straining through a suitable strainer or a piece of cheese-cloth. It is also claimed that it has been found suitable for use on parts based on Nylon, formvar and linen-wrapped wires, all metallic components, ceramic capacitors and resistors, as well as miniature and sub-miniature electronic tubes. Furthermore, it is not harmful to phenolic based systems, such as printed circuits. The solvent should be used with adequate ventilation, and in circumstances where prolonged or repeated breathing of vapour or contact with the skin is avoided.

zed relays. Telephone Manufacturing Co. Ltd., ulwich, London, S.E.21.

ype 51 Carpenter polarized relay is now available in asic versions two of which are "each-side-stable," i.e. 1A for d.c. applications, and type 51C for a.c. appli- s. The two other versions are "centre-stable" in appli and are designated type 51M (1 ampere-turn sensitivity), pe 51B (2½ ampere-turns sensitivity). All versions are d to have freedom from positional error; bounce-free t action; high thermal stability and small size. The ontacts form a single-pole change-over action and can ed with various materials. In general, contacts are at 10 W consistent with 1 A or 200 V peak.

tion microradiographic apparatus. Philips Electronics c., Instruments Division, 750 South Fulton Avenue, ount Vernon, N.Y., U.S.A.

-ray microscope employs an X-ray source of less than icron diameter and is capable of a resolution of one n or better at 2·20 kV. Direct magnifications up to n a photographic plate are possible, and up to 250× e viewing screen. The total useful photographic ement is claimed to be 1500×. The field of view at num magnification is about 0·5 mm and at 2× ification is about 15 mm.

or seven different targets may be used and these are hangeable during operation through external controls. pecimen chamber is arranged for air or vacuum ion and two specimen holders are provided which can modate specimens of $\frac{3}{16}$ in. and $\frac{5}{8}$ in. diameter respec- The specimen carriage is readily adjusted by controls exterior to the chamber. The camera is capable of recording five exposures on a 2 × 10 in. plate in the same medium (air or vacuum) as the specimen. Exposure times are said to be of the order of one minute at 10–12 kV.

The assembly is readily convertible to the Norelco type EM-75 electron microscope and the inverse conversion may also be made to existing EM-75 microscopes.

General purpose oscilloscope. Telequipment Ltd., Southgate, London.

The Serviscope is a comparatively inexpensive measuring oscilloscope designed for general laboratory use. It employs a 3 in. diameter flat-faced tube operating at 1·4 kV. The Y-amplifier is stated to have a sensitivity of 100 mV/cm and to be uniform to 3 dB over the frequency range zero to 6 Mc/s. The rise time is 0·06 μs. The input attenuator has nine ranges, from 100 mV/cm to 50 V/cm, which are direct reading in volts per centimetre. The input impedance is 1 MΩ and the accuracy of voltage measurement is stated to be 5%. The time-base has eighteen calibrated sweep speeds from 500 ms/cm to 1 μs/cm at minimum X-expansion. The time measurement accuracy is stated to be 10%. X-expansion is continuously variable up to over ten screen diameters, the trace expanding symmetrically about the centre of the screen. Any portion of the expanded trace can be centred on the screen by means of the X-shift control. There is direct access to the X-amplifier. Triggering is automatic for repetitive signals up to about 1 Mc/s, the trigger level control selecting any point on the input signal slope for repetitive, random or single-shot triggering.

New books

ss in semiconductors. Vol. 3. Edited by A. F. Gibson, . Aigrain and R. E. Burgess. (London: Heywood & o. Ltd., 1958.) Pp. viii + 210. Price 55*s*.

hird volume of *Progress in semiconductors* will be ned by all who are trying to keep up with the extensive t of research which continues on this subject. Perhaps o outstanding papers in this issue are those by J. W. ell on the electronic conductivity of silver halide ls, and by D. E. Mason and D. F. Taylor on silicon n diodes. Both are comprehensive, authoritative, and date. The paper by A. E. Many and R. Bray on life- of excess carriers and recombination processes will found of great value.

shorter papers on cadmium sulphide by J. Lambe and Klick, on the chemical purification of germanium and by J. M. Wilson, on the magnetoresistivity of ger- m and silicon by M. Glicksman, and on scattering and obility in germanium by M. S. Sodha, will perhaps ore limited appeal; the second of these gives details problems encountered in purifying a semiconducting al, while the others survey quite fully the present state wledge in their respective subjects.

D. A. Wright

nenbeugung. By E. Bauer. (München: Verlag oderne Industrie, 1958.) Pp. 233. Price DM. 32.

glory of the successes of electron-microscopy, electron ion has recently tended to become relegated into the ound, and Dr. Bauer's book is a timely reminder of the importance and, at any rate historically, rightful place of the subject. This book is written concisely, clearly, and to the point, and can be thoroughly recommended. It lays stress on practical applications in industry, but will appeal largely to the advanced student or researcher, a degree of mathematical and physical knowledge being assumed. A very full bibliography of some 600 sources fills any gaps there might be.

The theoretical part (60 pages) gives an excellent account of both electron-optical and crystallographic principles, in which the early introduction of the reciprocal lattice greatly assists. An attractive feature is a summary after each section, giving the salient "Why's." The experimental section adequately covers all aspects of equipment, and much detail and good advice is compressed into 100 pages, including helpful drawings and photographs; it is pleasant to note a non-parochial outlook (not always to be taken for granted), and a well-balanced comparison of British, American and Continental products and methods. The 40-page section on "Applications" covers both the fundamental and industrial aspects, and has a chapter each on electron diffraction in the metallurgical, chemical, electrical and optical industries, with an ample selection of examples.

The link-up with electron-microscopy is never forgotten, and the book ends with a brief account of diffraction of slow electrons, and of what is termed "Elektronenbeugungs-mikroskopie," dealing with selected-area examination by both methods combined. A welcome final feature is an extensive classified list of suppliers of manifold equipment.

H. J. Goldschmidt

Notes and comments

Medical electronics discussion group

An Interim Committee composed of members of The Institution of Electrical Engineers and of the medical profession, having a common interest in medical electronics, discussed at a recent meeting the scope and future activities of the Medical electronics discussion group which has been set up by the Council of The Institution.

It has been decided that the activities of the Group should be centred round advanced electronic techniques applied or related to medical and biological problems, and there will be a program of informal discussion meetings which will provide a forum for the exchange of information between the two professions on subjects coming within this field.

It is proposed to provide an opportunity in the course of each discussion meeting for members present to give notice of any problems which they have encountered (not necessarily related to the topic discussed at the meeting), in the hope that others present may be able to offer suggestions for their resolution.

A mailing list has been compiled of those who have expressed interest in the Group's activities. Any interested reader should send his name and address to the Secretary of The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Congress of the International Federation of Automatic Control, Moscow, 1960

The first International Congress of the International Federation of Automatic Control is to be held in Moscow from 25 June to 5 July, 1960. The British Conference on Automation and Computation has been asked by the Executive Council of the International Federation of Automatic Control for their co-operation in arranging for the submission of papers for the Congress from British sources and, in accordance with this request, the British contribution to the Congress will be co-ordinated through the General Committee of the British Conference on Automation and Computation with the assistance of its three Groups.

The Congress will cover the following three fields:

Section I, Theoretical and experimental investigations on automatic control and servomechanisms;

Section II, Instrumentation and investigations connected with the development of automatic control systems;

Section III, Industrial applications of automatic contro (including the application of prediction an computing devices).

The Congress will include: (*a*) the presentation and discussion of scientific reports, (*b*) excursions to scientifi institutions and also to various automatic undertaking (*c*) visits to centres of culture in Moscow.

Intending authors should submit abstracts of their propose papers, not exceeding 500 words in length, and not later tha 1 February, 1959, to Mr. W. Bamford, Honorary Secretary Group B, British Conference on Automation and Computation, c/o The Institution of Electrical Engineers, Savo Place, London, W.C.2.

The Physical Society's annual exhibition of scientific instruments and apparatus

The Physical Society announces that its forty-third ann exhibition will be held at the Royal Horticultural Society Old and New Halls, Westminster, London, S.W.1, fro 19–22 January, 1959 (inclusive).

Entrance to the exhibition is by ticket only and these ma be obtained, free of charge, from the offices of the Society 1 Lowther Gardens, Prince Consort Road, London, S.W.1 Members of The Institute of Physics may obtain tickets fro the Institute. The handbook of scientific instruments an apparatus published in connexion with the exhibition i available from the Society, price 6*s*.; by post 7*s*. 8*d*.

British Journal of Applied Physics

Contents of the December issue

SPECIAL ARTICLE

The choice of resilient materials for anti-vibration mountings. By J. C. Snow

ORIGINAL CONTRIBUTIONS

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Electrical properties of chalcopyrite. By B. Donovan and G. Reichenbaum.
A generalized theory of sedimentation. By A. D. Maude and R. L. Whitmor
Resistance bias characteristic of the electron microscope gun. By M. E. Ha P. A. Einstein and P. H. Borcherds.
The friction of mineral particles. By R. T. Spurr.
The magnetic stabilization of low pressure d.c. arcs. By H. Wroe.
The grid emitting properties of titanium. By J. A. Champion.
The influence of the method of demagnetization on the reversible permeability o a high-permeability nickel–iron alloy. By R. C. Jackson, E. W. Lee an A. G. H. Troughton.

NOTES AND NEWS

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Deuterium-filled thyratrons. From K. G. Cook and G. G. Isaacs.
Deuterium as a filling for high-voltage thyratrons. From R. J. Armstrong an N. S. Nicholls.
Notes and comments

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Orders and enquiries about the binding of back-numbers of the *Journal of Scientific Instruments* and of the *British Journa of Applied Physics* should now be sent direct to Messrs. E. A. Weeks and Son, 168 Gower Street, London, N.W.1 (EUSton 4674 and *not* to The Institute of Physics. This new arrangement does not involve any change in price.

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